metal treatment

Vol. 27 : No. 175 APRIL, 1960 Price 2/6

WILD BARFIELD NRC *

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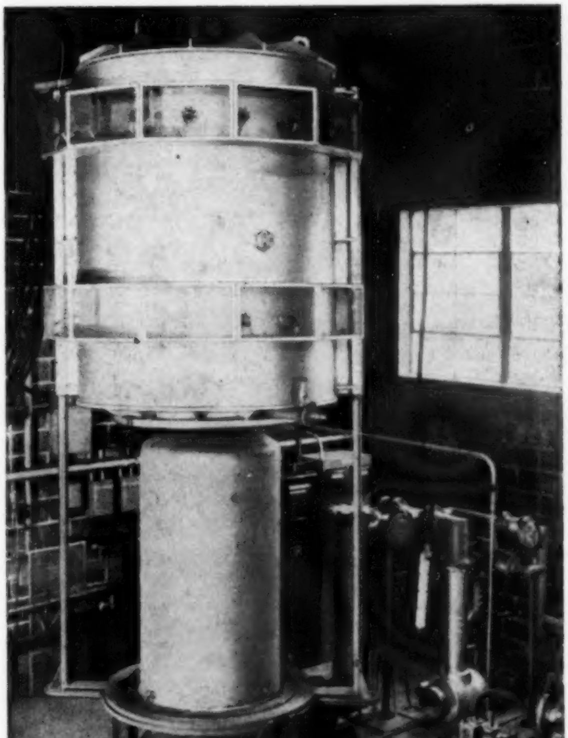

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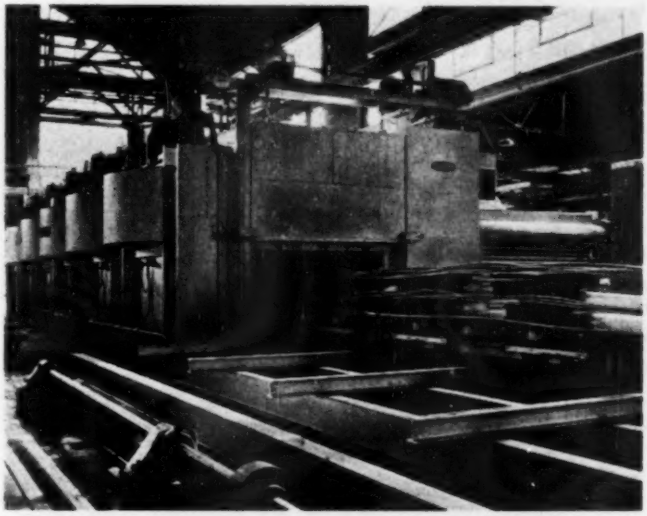
NRC3

G.W.B. high-rating furnace cuts cycle times



Accommodates slab lengths of 65 ft. x 6 ft. 6 ins.

In the recent large-scale development programme spread over some 30 months, the Northern Aluminium Co. Ltd. has introduced considerable quantities of new plant and handling equipment. A new batch-type furnace, designed and erected by G.W.B. at the Banbury Works of Northern Aluminium, was part of this programme. Production at Banbury, both in aluminium and a variety of aluminium alloys, embraces a wide range of sheets, discs and coils.

Owing to the occurrence of a certain amount of work-hardening (8 in. thick ingots of aluminium are hot rolled to a thickness of approximately 0.3 to 0.5 in.) it is necessary for slabs to be annealed prior to being cold rolled to lighter gauges. The rating of this G.W.B. furnace is 1,000 kW and it comprises six independent and automatically controlled zones of equal length. Rating distribution is as follows: Zone 1 220 kW, Zones 2-5 150 kW each, Zone 6 180 kW. *Owing to the high rating, cycle times as low as 4 hours are regularly obtained.* The maximum temperature of the furnace is 600°C, normal operating temperature being rather lower than this figure.

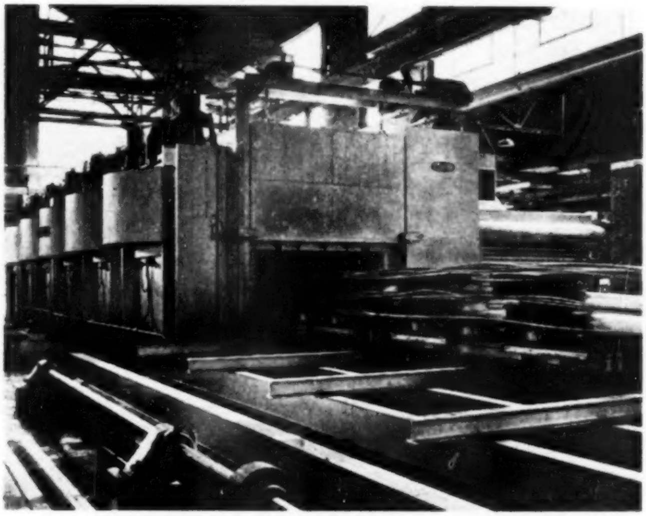
The heating chamber is lined throughout with heat-resisting alloy, backed by a thick wall of Moler insulating bricks, thus reducing heat losses to a minimum. The furnace casing is constructed from sheet mild steel braced with steel rolled sections and fitted with a mild steel front plate. A cast-framed, refractory faced, fully insulated and counter-balanced door, driven by electric motor, is sealed against the furnace face by pneumatic clamps, thus minimizing heat losses at the furnace entrance. The furnace is supported clear of the ground.

Nickel-chromium strip heating elements, arranged on removable plugs, are situated in the roof chamber, and each zone is fitted with a forced-air circulation system directed cross-flow from the fan, through the heating elements contained in the ducted portion of heating chamber, down into the treatment chamber, and back into the fan for re-circulation. Radiation on to the charge is prevented by a special baffle fitted in the roof chamber to separate the heating elements from the actual working area. Baffles, each independently adjustable and extending the full length of the chamber on each side, direct the air flow to give desired flow characteristics and equalise the temperature throughout the working chamber.

Six air circulating fans are fitted, one per zone. A cooling chamber, similar in size to the heating chamber is incorporated in the unit. A G.W.B. single track charging machine serves both the furnace and the cooling chamber.

As a result of the modernisation, the new rolling mills can roll aluminium sheet to a maximum width of 6 ft. 6 in.; the previous maximum had been 5 ft. The G.W.B. furnace naturally was designed to handle this increased width. It can accommodate loads up to 16 tons for slab lengths of 65 ft. The furnace is normally used to treat slabs of heavy-duty materials for varied employment: Aircraft, coachwork, decorative finishes, car trimming and a host of other uses.

G.W.B. high-rating furnace cuts cycle times



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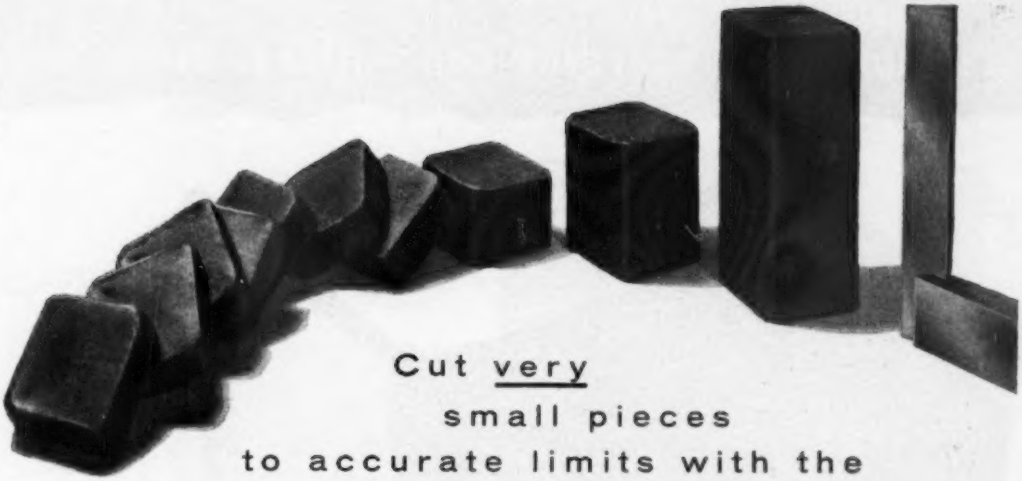

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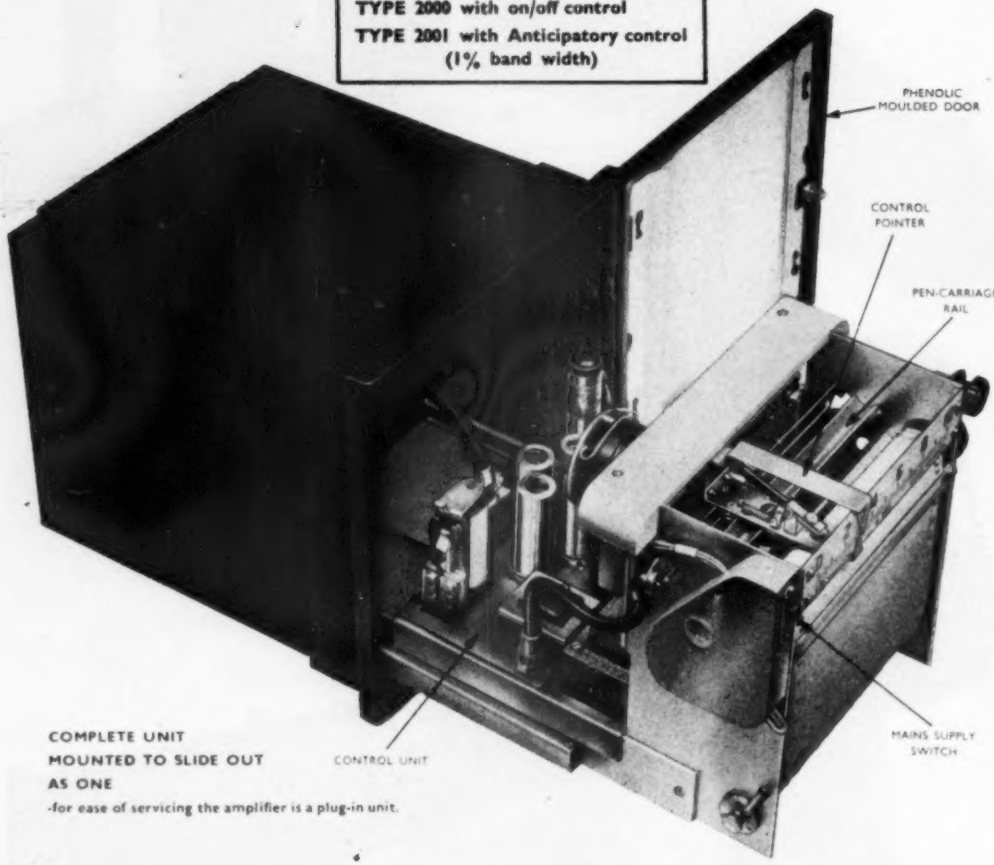

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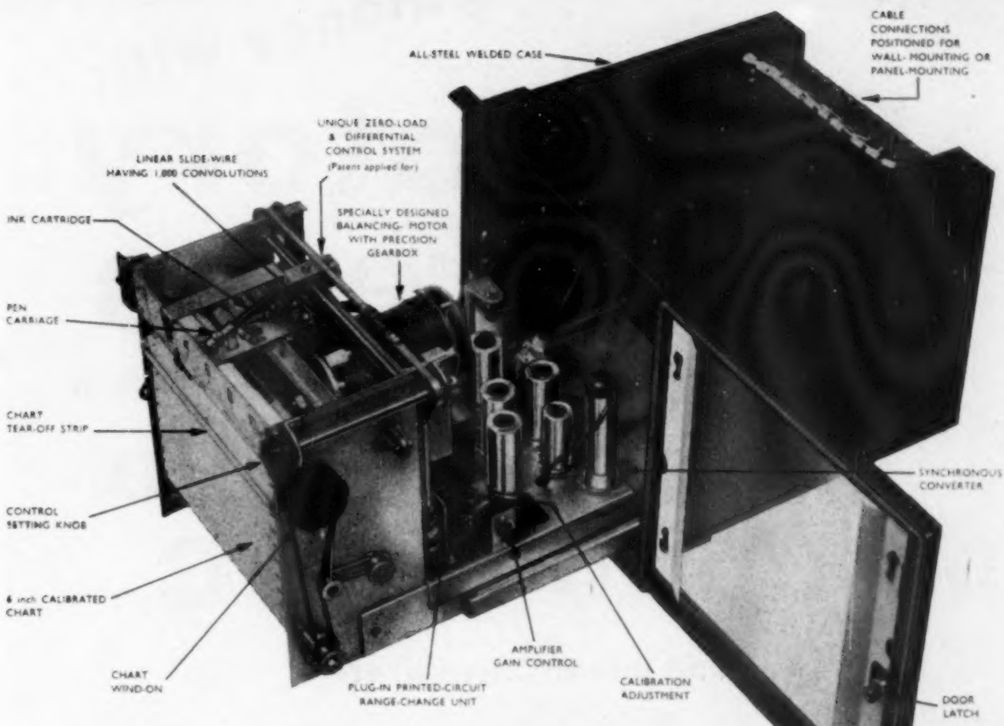

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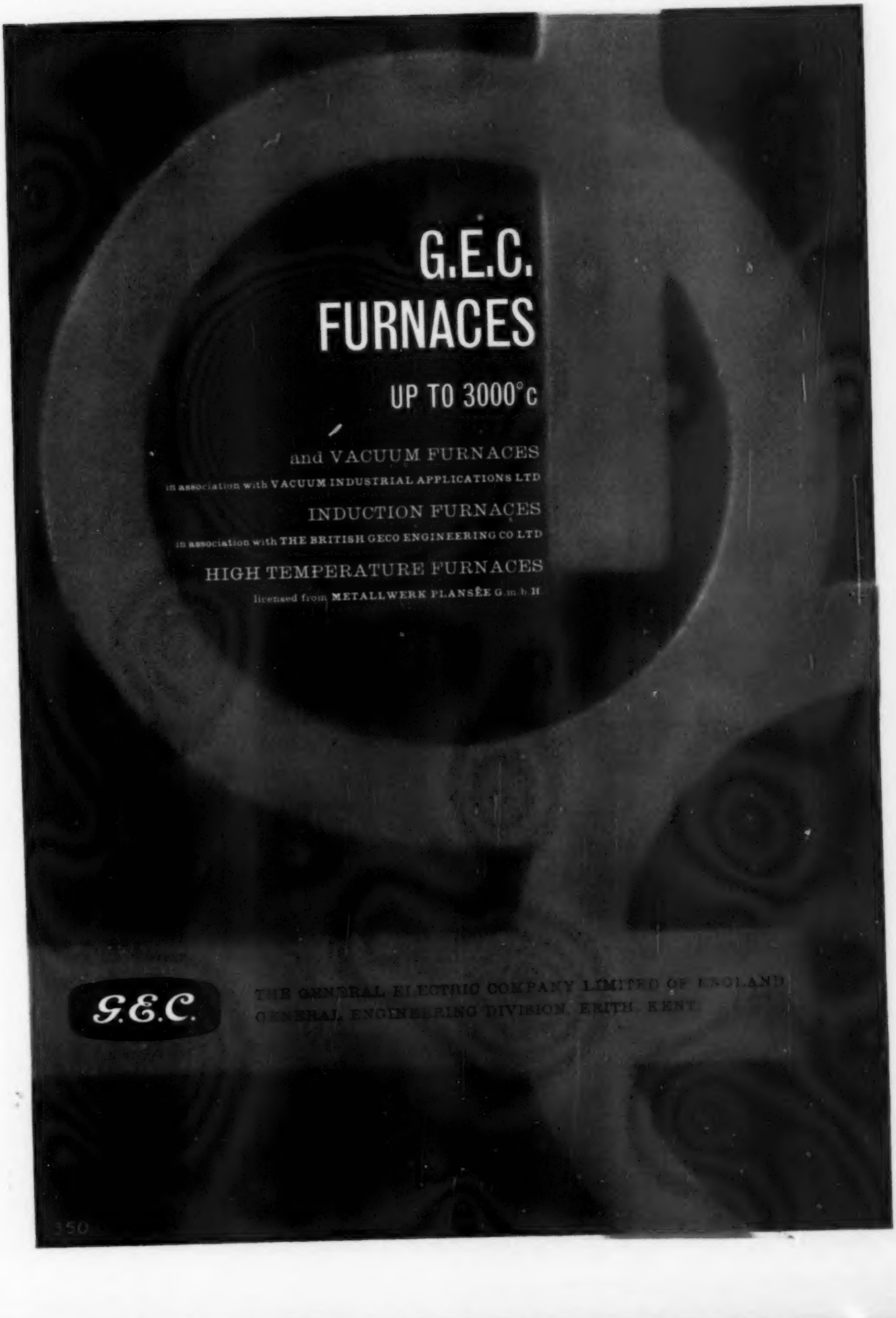
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April 1960

Vol 27, No 175

metal treatment

and Drop Forging

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CONTENTS

This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

Metals of tomorrow

WRITERS of science fiction are adepts at perfecting new and wonderful alloys for the brave new worlds of their dreams, and looking at the achievements with the newer metals during this century who can blame them? Nevertheless, in spite of new metals and special alloys, it is clear that availability and price will always give our more common metals a great advantage and makes any possible improvements specially interesting. The determining factor in the widespread use of these metals is, of course, our ability to control strength and ductility and to vary these within wide limits. Recent work on dislocation theory has led to noteworthy advances in our understanding of plastic flow and may well effect considerable changes in metal working of the future.

An assessment of future possibilities arising out of some recent discoveries was given at the last autumn meeting of the Institute of Metals in Stockholm by Professor E. G. Rudberg, secretary of the Royal Swedish Academy of Sciences. Professor Rudberg believes that the study of the physics of dislocations will enable the metal industry of the future to formulate methods of regulating plastic flow that are safer, more advanced and time-saving. It should also stimulate the development of materials better suited to manipulation than are those used now. These metals, suggests the professor, will still probably be the metals now commonly in use and not new materials altogether.

Professor Rudberg then goes on to discuss the possibility of avoiding dislocations altogether in metals. 'If one could produce a metal that neither contained dislocations nor gave rise to them, then enormous strengths should become available. This has been clearly demonstrated in the spectacular experiments on metallic whiskers carried out in recent years. Whiskers are very thin filaments, often consisting of single crystals, grown by special techniques. If no dislocations lie concealed in the surface, or develop there, the elastic range of such a filament under tension becomes simply fantastic. Iron whiskers, for example, have behaved elastically up to 5% elongation. This means that they are completely resistant to stresses of 14 million lb./sq. in.—some fifty times the best tensile strength now available.

'Can these significant effects be harnessed for practical use in the future? To begin with, is it conceivable that metals in larger pieces could be obtained free from dislocations? The answer is "Yes." Dislocations are, in fact, thermodynamically unstable arrangements in the crystal. Without them the metal would be more stable and have less free energy. In principle, therefore, dislocations should move out of the metal or evaporate under really intelligent heat treatment.

'It seems relevant to remark that in the metal industry an ever-increasing importance is being attached to surface condition. This is especially true, I believe, on the mechanical side. Hence the efforts directed to obtaining a high finish on cold-rolled stock and the care exercised in controlling furnace atmospheres and surface-hardening treatments, including various cementation processes. It is known, too, that metal fatigue depends critically on the state of the surface layer. If strengths comparable to those of whiskers are to be achieved and maintained, the requirements relating to surface finish may well be pushed one stage further.'

Professor Rudberg emphasizes his belief in the importance of research of all kinds—fundamental university type as well as that offering immediate industrial application. He sums it up aptly in his concluding remarks '. . . when X-ray work revealed a model of solids that should withstand a load a hundred times greater than that actually observed, this did not seem of much importance to constructional engineers. It will therefore probably take more than a few almost invisible metallic whisker filaments to convince the world that the strength of nearly perfect solids has more to it than mere theoretical interest.'

LETTERS *to the Editor*

Electron microscopy

SIR: In the January, 1960, issue of METAL TREATMENT there is an article entitled 'A simple extraction replica for the study of fine grain phases' by Jaroslav Jezek. Having read the article, I can only assume that both the author and yourselves are unaware that the method is substantially that developed in the physics department of these laboratories in 1954–55. Details of this method were given in contributions to internationally known British scientific journals, a not inconsiderable time before Jezek's contribution to *Hutnické Listy*, 1958, (3).

Our original contributions were completed in June, 1956, and published in the *Brit. J. Appl. Physics*, 1957, **8**, 109–113, and **8**, 155–157. As early as September, 1957, I read a paper at the annual conference of the Electron Microscopy Group of the Institute of Physics, before an international audience, which gave details of a general scheme for the examination of precipitates and inclusions in steel. This paper excited a great deal of interest and was published in *Brit. J. Appl. Physics*, 1958, **9**, 361–365.

Subsequently published work has shown that versatility and wide application of this method.

J. NORBURY

Richard Thomas & Baldwins Ltd.,
Central Research Laboratories,
Whitchurch, Aylesbury, Bucks.
February 12, 1960.

SIR: I am glad to see that the simple extraction replica method is used also by English workers. As a propagator of this method in electron microscopy in Czechoslovakia, I read with satisfaction of the interest excited by Mr. Norbury's paper at the annual conference of the Electron Microscopy Group in 1957.

Mr. Norbury has described an extraction replica method in which he used the composite films Formvar plus collodion. I am using a rather more simple method with one film (collodion) which I strip by means of a glue-paper. Only in one place of my paper is made the remark about the possibility of reinforcing the basic replica with a further layer (as Mr. Norbury does). So we both had the same idea, although Mr. Norbury was the first with its realization.

As I know, a lot of varieties of the single-etch method have been used by workers of many countries and each of them prefers his own. But it is true that Mr. Norbury published the details of his method in 1957. We developed our method in 1956–57 and sent the details of it, together with some applications, to *Hutnické Listy* in July, 1957, not knowing the paper of Mr. Norbury. Later, in my Research Report VUMT, No. 565, Mr. Norbury's paper was cited as reference No. 56.

J. JEZEK

Opletalova 25, Praha 3, Czechoslovakia.
March 30, 1960.

Furnace temperature uniformity

SIR: We were interested in the article headed 'Temperature uniformity in heat treating' in the February issue of your journal. Your readers may be interested to know that considerable improvements in uniformity of heating can be achieved by careful control of the furnace pressure. It is true that the type of furnace referred to by your contributor is of the muffle type, that is to say, the products of combustion do not enter the work chamber, but in those cases where the products are allowed to enter the work chamber and circulate amongst the load a very much more uniform temperature can be achieved throughout the whole furnace by the adoption of automatic furnace-pressure control.

It has been shown in tests that whereas with a pressure of +0·01 in. w.g. differences of 15°C. at 900°C. are evident, these differences are reduced with increasing pressure until at a pressure of +0·07 in. w.g. and over there are no differences at all. Similarly, for temperatures in the region of 760°C. and with a pressure of −0·01 in. w.g. differences of 25°C. exist but these are reduced by increasing furnace pressure until at pressures of above +0·05 in. w.g. there are no differences at all.

This is, of course, only one of the advantages of automatic furnace pressure regulation, but it seemed to us that your readers may be interested in connection with the excellent article by your contributor.

A. WRIGHT

Electroflo Meters Co. Ltd.
March 4, 1960.

SIR: Mr. Wright's comments on the advantages of pressure control in directly-fired furnaces have considerable interest and certainly practice shows them to be well founded. Although perhaps in a different field from the chief concern of the article on which he comments, it is a useful point well worth more attention. I would question perhaps that with all furnaces automatic uniformity of temperature can be produced by increasing the pressure; this is far from true in many cases. I would certainly question with many furnaces the possibility of achieving high pressure internally.

Achieving internal furnace pressure is, of course, of even more vital importance in atmosphere furnaces to prevent infiltration of air. This is not always achieved as well as it should be, and careful check on internal furnace pressures should be one of the points of judgment on various designs of atmosphere furnace. I think Mr. Wright has done well to call our attention to this not too frequently measured but very important aspect of furnace operation.

T. W. RUFFLE

Ipsen Industries Inc.

Specimen grinding

An addition to the range of metallurgical equipment manufactured by Nash & Thompson Ltd. has been designed to provide a simple method for wet or dry grinding of specimens.

The grinder consists of a ground-glass plate and a perspex frame for holding four grades of waterproof abrasive papers which are washed continuously by water sprays incorporated in the head of the perspex holding frame. The assembly is mounted in a polythene tray with a drain exit.

Specimens up to 1¼ in. dia. can be ground in the normal manner, and it is recommended that they be turned through 90° after each paper. A slower grinding speed with an increased pressure is recommended to take full advantage of the wet grinding technique. Worn papers are replaced in a few seconds.

Application of electron microscopy

Hardened and tempered mild steel structures

STEN MODIN

Three types of low-carbon steel have been heat treated and the mechanical properties compared with those obtained after normalizing. The structures were examined both in an optical and an electron microscope. This work was first reported in Swedish in 'Jernkontorets Annaler,' 1959, No. 6, and the present version will be continued next month. Mr. Sten Modin is with the Swedish Institute for Metal Research, Stockholm

IN 1947, in the research committee of Jernkontoret, B. D. Enlund took the initiative for the present research work and proposed that the work should be undertaken in the following words:

'During research into the ageing properties and sensitivity of mild steel to so-called caustic brittleness, it has been shown that the structure which is produced by quenching and tempering to high temperature to a great extent reduces the susceptibility of steel to both ageing embrittlement and caustic brittleness.

'The conditions of the formation of this structure have, however, never been the subject of intensive research, and a programme of research in this field seems to me to be well warranted.'

B. D. Enlund had long had great interest in the hardened structure of carbon steel, and by means of other physical methods, such as measurement of the electrical resistivity and microscope investigations, had acquired an extensive knowledge of the subject.[1, 2, 3, 12] He had hoped to be able to do further work in this sphere through the present research project. He did not have the opportunity to fulfil the task, however, since in the spring of 1950 he was forced to break off the work on health grounds. Since then, the author has been joined on the research committee by P. M. Sjöberg, G. Sehlberg, C.-H. Rosendahl and T. Norén.

The research work has covered two carbon steels with respectively 0·09 and 0·18% C with a normal, low content of manganese, and also a steel with 0·19% C and an Mn content of 1·16%. The structures investigated have included those of fully hardened specimens, and additionally those of specimens which were afterwards tempered. The tempering temperatures chosen have included a series of temperatures from 200–700°C. at intervals of 100°C. In all instances the tempering time was 1 h. The structures resulting from the heat treatment were examined both in an optical microscope and, after production of the replicas, in an electron microscope. Apart from this, carbide particles isolated by chemical means from some of the specimens of the steel containing 0·18% C were directly investigated in the electron microscope. At the same time electron diffractographs were taken to determine the lattice structure of these carbide particles.[14]

The mechanical properties of the three types of steel after the heat treatments mentioned were compared with those obtained after normalizing. Apart from this, it has been endeavoured to trace the connection between the mechanical properties and the structures. The research also covered such structures as occurred when specimens of the steels did not become fully hardened during quenching.

Earlier investigations

The formation of martensite and also the tempering of martensite have been, and continue to be, subjects for numerous investigations. A comprehensive literature review of new research results has recently been made by Kehsin Kuo.[4] G. Folke and E. Nygren[5] have published a work in which a special study was made of the range of existence of ε-carbide and of cementite during the tempering of martensite in steels with differing carbon contents.

Most of the investigations of the mechanism of the formation of martensite, as well as of the tempering of martensite, have been carried out by X-ray diffraction methods. Optical microscope investigations of polished and etched surfaces are less well suited in this work, since the carbide particles

formed during the tempering of martensite at low temperatures proved to be so small that they were beyond the powers of resolution of the microscope even at its highest magnification. On the other hand, it is remarkable that hitherto only a small number of investigations have been carried out by means of electron microscopy and electron diffractography. In order to follow the sequence of the tempering of martensite physical methods have also been employed, such as measurement of the electrical resistivity, dilatometric investigations and also the calorimetric method.

Most of the investigations of the structure of martensite and of the structures which form during its tempering, cover as a rule steels with higher contents of carbon than 0·3%. The works which deal with low-carbon material are comparatively few, and the results are less reliable than for steel with a higher carbon content.

A short summary of literature containing the most important results for this investigation will be given below. Martensite can be described as an enforced solution of carbon in alpha iron, in which the carbon atoms occupy lattice spacings in such a way that the otherwise space-centred cubic lattice of alpha iron is extended along one of the axes of the cube and somewhat shortened along the other two axes, so that the lattice becomes tetragonal. The way in which the transformation from austenite into martensite occurs in detail is still the subject of current investigations. In an optical microscope martensite makes its appearance with a characteristic needle-like structure. In the untempered state the martensitic structure is considered to be hard and brittle, and therefore often unsuitable for structural components. More recently, however, the view has been expressed that the martensite which is formed in low-carbon steels possesses both good strength and toughness.[6]

Martensite is formed from austenite during the cooling of the latter below a certain critical temperature, M_s. When the M_s point is passed, an inconsiderable quantity of martensite is instantaneously formed. Since the formation of martensite is dependent on temperature but not on time, the quantity of martensite increases only when the temperature falls. The level of the M_s temperature is mainly dependent on the carbon content, and the level of alloying, of the austenite. In particular an increased content of carbon lowers the M_s point. In steel of the type which is the subject of this investigation, the temperature of the start of the formation of martensite will lie at a high level of about 400°C. and above, on account of the low contents of carbon and alloying elements in the material under investigation. Martensite which is formed at such a high temperature, can be considered to acquire a certain degree of tempering as it cools. A tempering process of this type is, meanwhile, normally referred to in English literature as Q-tempering or self-tempering. Where such a form of tempering of martensite with a low-carbon content takes place, it has been shown that a carbide phase is formed. Aborn,[6] by means of electron diffraction, investigated this carbide and found it to be cementite. His electron micrographs of these cementite particles showed that they had the form of short rods. To judge from the location on the plastic replicas of the detached carbide particles, they must presumably have formed within the acicular crystals of martensite.

The change in the hardened structure during the tempering of steels with a carbon content in excess of 0·3% is considered to proceed in three stages, which are dependent on both temperature and time, and partly take place simultaneously.

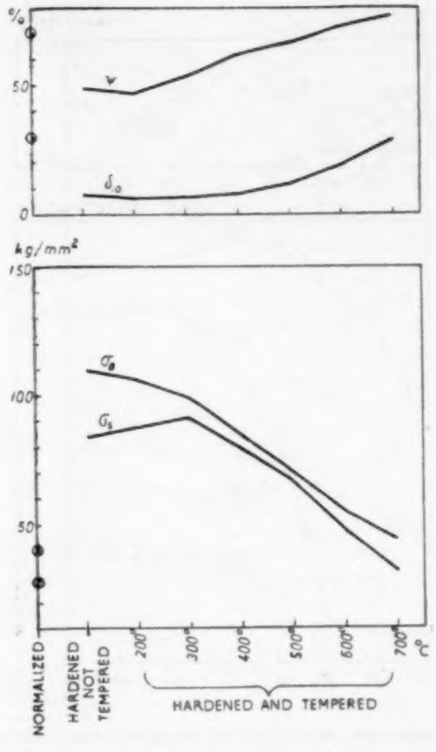
First stage. Precipitation of ε-carbide out of the martensite, so that the carbon content of the latter falls to about 0·25%.

Second stage. Transformation of the residual austenite into bainite.

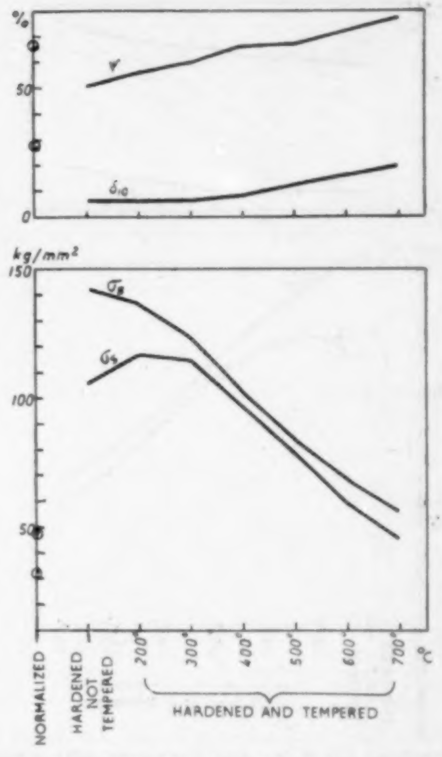
Third stage. Precipitation of cementite, causing a further decrease in the carbon content of the matrix.

To what extent the mechanism of tempering indicated above likewise applies to low-carbon, unalloyed steels, is a matter of doubt. Thus, for instance, stage 2 must well be of no consequence, since the content of residual austenite is particularly low or is completely non-existent in this type of material. It has not proved possible to indicate experimentally the occurrence of stage 1, the precipitation of ε-carbide.[6, 7] During the tempering of low-carbon, unalloyed steels, therefore, only stage 3 is considered to occur, namely the precipitation of cementite and the formation of ferrite, low in carbon.

Aborn[6] has recently shown that both low-carbon steels which are hardened only, and also those which are both hardened and tempered, have good physical properties. He likewise showed that it was possible to obtain tensile strength values of 100 kg./mm.^{2} (63·5 tons/sq. in.) and over, if these steels are hardened. Likewise the yield strength lies at a high level. The values for the elongation and the reduction in area were at the same time good, about 10 and 60% respectively. If a hardened steel of this type is tempered at temperatures above 400°C., then good values are obtained for the impact strength down to −50°C. and even lower temperatures. In the untempered condition the material had moderate impact strength. On the other hand, tempering in the temperature range of about 300°C. frequently produced an obvious embrittlement of the material, so that the impact strength values might in some instances be at a lower level than



1 *Tensile test SIS 5C50. Steel D in various states of heat treatment*



2 *Tensile test SIS 5C50. Steel E in various states of heat treatment*

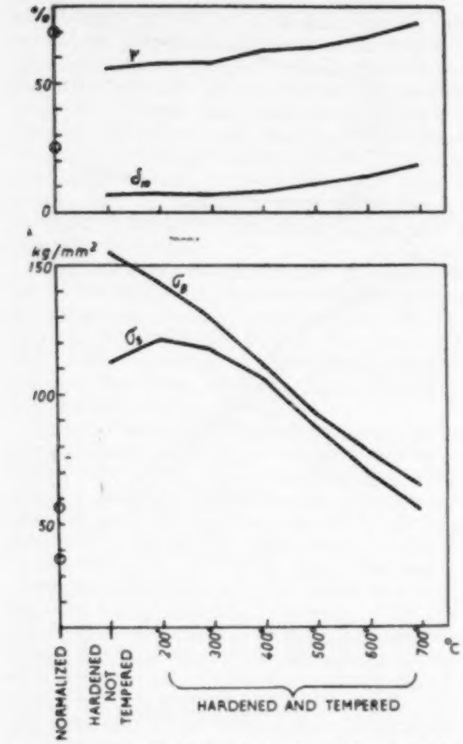
for the same material in the hardened, but untempered state. The cause of this embrittlement has not been made clear, although a number of suggestions have been put forward.[6, 13] Thus it has been indicated *inter alia* that the extremely fine precipitation of carbide particles which occurs within this range of temperatures should have some connection with this embrittlement.

Experimental material

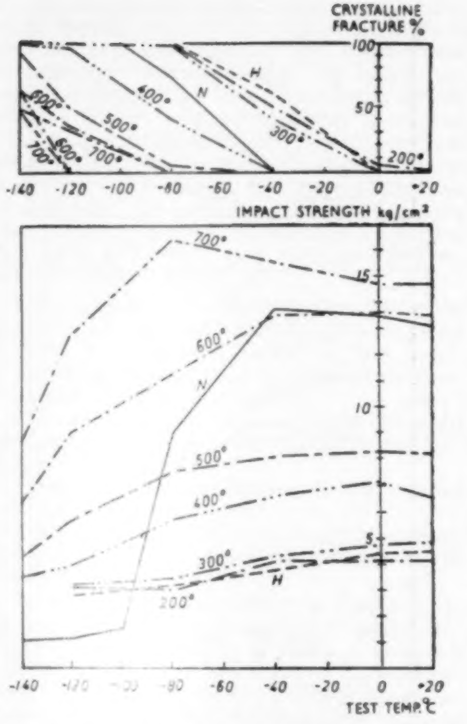
Investigations were carried out on three steels from the steelworks Degerfors with the analyses given below.

A spectral analysis determination of the remaining foreign inclusions in steel E showed that only inconsiderable traces of these existed. Steels D and G were killed basic electric furnace steels, while steel E was a killed basic open-hearth steel. Steel D represented a steel of 37 kg./mm.² (23·5 tons/sq.in.) tensile strength, E a steel of 44 kg./mm.² (28 tons/sq. in.), and G a steel of 52 kg./mm.² (33 tons/sq. in.), before heat treatment. The material was originally in the form of round rolled bars of 20 mm. dia. After normalization, D at 930, E at 910 and G at 885°C., the dia. of the bars was reduced 1 mm. by machining, so that the external, decarburized layer should be removed, and the specimens were then taken from the bars.

Steel marked	C	Si	Mn	P	S	Cr	Ni	Cu	Al_{sol}	Al_{insol}	N
D	0·09	0·19	0·31	0·009	0·044	0·05	Trace	0·21	not determined		
E	0·18	0·31	0·47	0·017	0·029	0·05	0·08	0·21	0·001	0·004	0·005
G	0·19	0·23	1·16	0·024	0·038	Trace	Trace	0·18	not determined		



3 *Tensile test SIS 5C50. Steel G in various states of heat treatment*



4 *Impact tests. Steel D in various states of heat treatment*

Mechanical testing

Preparation of the specimens

From the normalized bars test bars were prepared; for the tensile test, bars of 5 mm. dia., and for the impact test completely cylindrical specimens of 55 × 5 mm. dia. By making the test-pieces so small in dia., during the quenching of the test-pieces from the hardening temperature in a solution of NaOH it was possible to obtain a completely martensitic structure, to judge from checks on the structure in the optical microscope.

The test bars, when ready for heat treatment, were quenched, steel D from 930, E from 910 and G from 885°C. in a 5% solution of NaOH at room temperature. Tempering took place at a series of temperatures from 200–700°C. at intervals of 100°C. Tempering time was 1 h. After heat treatment the tensile and impact test specimens were cleaned off with emery cloth, and afterwards a 1-mm. Izod indentation was made in the latter.

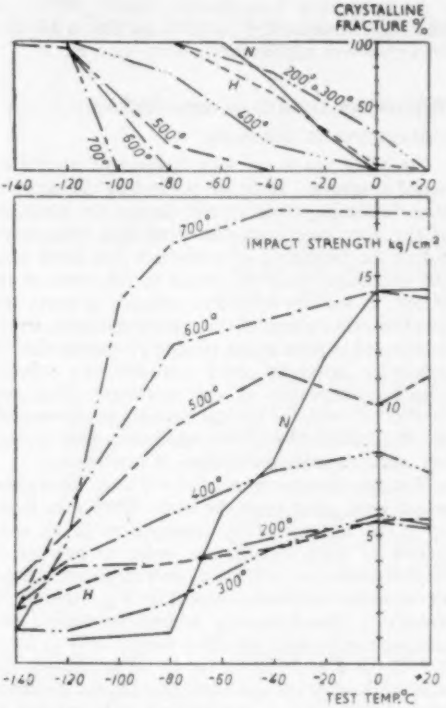
For each state of heat treatment two tensile test-pieces were prepared. For the material which was quenched only or that which was quenched and then tempered at 200 and 300°C., it was difficult to determine the yield strength. In these instances the 0·2% proof stress was determined in accordance with the dividers method and in two instances in accordance with offset method.

The impact tests were carried out at a series of temperatures from −185 to +85°C. The appearance of the fractures of the test bars under such circumstances covered the complete range from 100% ductile to 100% brittle fracture. In general two specimens were fractured at each experimental temperature, and in some instances several.

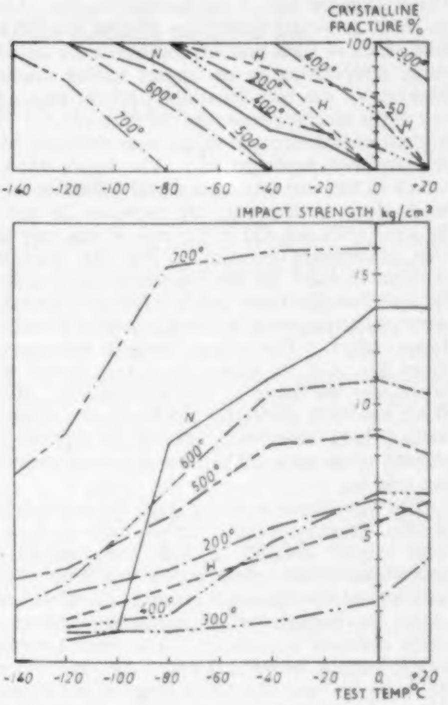
Tensile test results

The values obtained from the tensile tests may be seen from figs. 1–3. It is evident that both hardening alone and also hardening and tempering together have a marked influence on the mechanical properties of these steels.

After hardening alone, both *the tensile strength and yield strength* of all three steels lay about three times



5 *Impact tests. Steel E in various states of heat treatment*



6 *Impact tests. Steel G in various states of heat treatment*

as high as in the normalized state. Where tempering followed the hardening, the yield strength fell almost continuously with the increase in the tempering temperature. After tempering for about 1 h. at 700°C. the tensile strength still remained higher than after normalization. The curves for the yield strength have, by comparison with the tensile strength curves, a somewhat deviating appearance. As a result of tempering within the range of 200–300°C., the yield strength was at a higher level than after hardening alone. Possible causes for this circumstance will be discussed later. After tempering at 400°C. the yield strength lay somewhat lower than after hardening alone, and fell continuously with the increasing tempering temperature.

After hardening alone the *value of the reduction in area* for all three steels went up to about 50%. During tempering the value for the reduction in area rose successively, and after tempering at 700°C. lay at a higher level than the value for the normalized test-pieces, despite the fact that the tensile strength and the yield strength lay at a higher level than for the normalized specimens.

The *elongation* after hardening had fallen to somewhat under 10% from 25–30% for the normalized specimens. On tempering above 300°C. the elongation values then rose successively, but even after tempering at 700°C. did not fully attain the values for the normalized specimens. On the tensile test-pieces which were subjected to hardening treatment, even at an early stage necking occurred during extension, and during the continuation of the test in practice all the deformation took place at this point, and for this reason the moderate elongation values were obtained. On the test-pieces, on the other hand, which were normalized, initially an even extension occurred along the whole of the bar, and only later did necking take place. For this reason the higher elongation values were obtained.

Impact test results

As mentioned earlier, impact tests were carried out on bars with an unusual shape, namely round bars of 5 mm. dia. with a 1-mm. Izod indentation, *i.e.* with a sharp notch. The small dimensions of the bars were chosen so that they should be fully hardened. The notch was made for the following reasons. During the first tentative planning of the

shape of the test bars, it was decided that they should be made as 5-mm. round bars without a notch. A trial series of such heat-treated bars were tested at room temperature in an impact testing machine. Not one of the bars fractured. All the bars came out of the machine bent into the form of a U. The highest impact strength values were obtained, when the bars were hardened only. The values obtained, which in this instance are a direct indication of the work done in bending, lay between 26 and 32 kg./cm.^{2} (370 and 455 lb./sq. in.). It was only after this preliminary experiment that the committee decided to make the test conditions more arduous by introducing a sharp notch. The test bars which were given this notch produced quite different and lower values. The values obtained may be seen from figs. 4–6, in which, as a rule, every point represents the mean of two experiments. Where there was wide discrepancy between the measured values, both have been plotted in the diagram instead of the mean value. Some curves, therefore, are double.

The normalized materials gave the usual characteristic impact-strength curves with a zone of high impact strength at high test temperatures and a zone of low values at low test temperatures, with an intervening transition zone. After hardening alone, the impact strength curve acquired an entirely different appearance. The impact strength values remain between 3 and 5 kg./cm.^{2} (43 and 71 lb./sq. in.) over the whole range of test temperatures with a slight rise towards the higher test temperatures.

At test temperatures above 0°C. the appearance of the fracture on the specimens which were hardened only was completely ductile, but at –80°C. completely crystalline. At the intervening temperatures a mixed appearance of the fracture was obtained.

Tempering at 200°C. had little influence on the impact strength. On the contrary, tempering at 300°C. produced a marked deterioration in its value for steel E, and even more so for steel G. Possible causes of this deterioration will be discussed later.

After tempering of the test-pieces at 400°C. and above, rising values are obtained for the impact strength, particularly at the higher test temperatures. The shape of the impact strength curves in this way came to resemble to an ever-increasing extent that of the curves obtained after normalization. At a tempering temperature of 700°C. the range of maximum values of the impact strength lay throughout its whole extent at a higher level than that for the corresponding normalized steels. The transition zone from the low to the high values was markedly displaced towards low test temperatures by comparison with that of the corresponding normalized materials.

At tempering temperatures above 400°C. the transition from ductile to brittle fracture is displaced towards lower experimental temperatures.

Microscope structural investigations

PREPARATION OF SPECIMENS

Tempered specimens with completely martensitic, initial structure. In order to prevent the austenite from becoming transformed during the quenching of the specimen from the hardening temperature before the formation of martensite had taken place, the specimens were produced in the form of thin plates. A sodium-hydroxide solution at room temperature was chosen as the cooling medium, since it is believed to have better cooling properties than the otherwise normally used common salt solution. Check observations of the structure which were carried out with the optical microscope showed that the structure in these plate specimens after quenching was composed exclusively of martensite.

The specimens consisted of 0·8 mm. thick plates, which were taken from the bars. They were heated up to the austenitization temperature in an atmosphere of pure nitrogen in order to prevent decarburization and oxidation, and then quenched in an aqueous solution containing 5% sodium hydroxide. The following normal hardening temperatures were used for these steels: 950°C. for D, 910°C. for E and 885°C. for G. The holding time was 5 min. after the specimen reached the hardening temperature. One specimen from each steel was not tempered. The rest of the specimens were tempered in a tempering bath at a series of temperatures at intervals of 100°C. from 200–700°C. for a period of 1 h.

For investigation of the structure, the specimens were ground and polished on one of the flat facesf Etching was carried out either in a 2% solution o. nitric acid in amyl alcohol or in a 4% solution of picric acid in ethyl alcohol. The difference in the etch patterns from these two etchants will be described later. For the electron microscope structural analysis the production of the replicas was carried out in the manner previously described.[8]

Partially hardened test-pieces. The partially hardened test-pieces were produced by quenching from the austenitization temperature a sufficiently long piece of the already mentioned normalized bars in a 10% solution of common salt. The hardening temperature was that normal for these steels, namely 950°C. for D, 910°C. for E and 885°C. for G. After the ends were cut off, the remainder of the test-piece was cut in the middle along the central axis. The plane surfaces obtained in this way were prepared for microscope structural analysis.

to be continued

Hot working of plain carbon steels

Factors influencing working characteristics

R. ROLLS, M.Sc., A.I.M., A.M.Inst.F., and the late Prof. A. PREECE, M.Sc., F.I.M.

The influence of residual copper, tin and nickel, furnace atmosphere and forging temperature on hot-workability was investigated by a hot-bend test at 1,060°C. and 1,180°C., after soaking for six hours at 1,150°C. in a neutral atmosphere (80% N_2, 10% CO_2, 10% H_2O) with additions of 4% free oxygen and/or 0·1% SO_2. Surface cracking was greater at 1,060°C. than 1,180°C. The severest cracking in copper-free steels (0·2% C) occurred after soaking in sulphur-containing atmospheres and forging at 1,060°C. In copper-containing steels, cracking increased with increasing copper content (up to 0·60% Cu), after soaking in all atmospheres except the neutral atmosphere containing SO_2, whereupon cracking was negligible. Residual tin (up to 0·060% Sn) had no significant effect on cracking tendency; 0·058% Sn in a steel containing 0·2% Cu only slightly increased the cracking tendency; 0·15% Ni in a steel containing 0·2% Cu and 0·02% Sn increased the degree of cracking after soaking in a neutral atmosphere containing sulphur-dioxide. Mr. Rolls was a research student of the late Prof. Preece at the Department of Metallurgy, University of Durham, King's College, Newcastle upon Tyne

THE HOT-WORKING characteristics of plain carbon steels may be adversely influenced by residual elements, reheating furnace atmospheres and forging temperatures. Such factors govern the rate and products of scaling, which ultimately determine the chemical and physical properties of the metal/scale interface. Many attempts to correlate the hot-working properties of a scaled surface with the factors governing scaling are often only of empirical value.

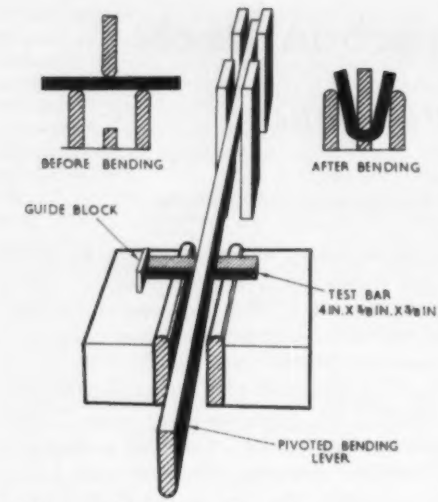
Since the end of the 17th century, observations have been made on the embrittling effects of copper in steel during hot working. Recent work in Germany by Born[1] has shown that this effect of copper can be minimized by introducing sulphur into the reheating furnace atmosphere.

In view of differing claims in the reported work on the effects of residual copper, tin and nickel in steel and of sulphur in the furnace atmosphere, the present investigation was undertaken to attempt to clarify the separate and combined effects of residuals in various furnace atmospheres.

Previous work

A comprehensive review of the early work concerning the association of residual copper with hot shortness in steels is given by Gregg and Daniloff.[2] There was little agreement as to the maximum permissible copper contents for trouble-free hot-working and figures quoted range from 0·3 to 4·5% Cu. However, these early investigations did suggest the importance of temperature and manner of forging, and the effect of alloying elements, in addition to copper, in controlling the degree of hot shortness during forging.

From about 1939, various attempts[3, 4] were made to account for the surface features associated with hot shortness and investigations became more selective, in that specific compositions, temperatures and treatments were taken into consideration. Even so there was still some uncertainty as to what constituted a 'critical' amount of copper to produce surface cracking. In 1942, Eberle[5] demonstrated that a 0·3% C steel with 0·25 to 0·3% Cu showed preferential surface oxidation of the iron accompanied by the formation of a low-melting-point copper-rich phase under a layer of iron oxide. Any distortion of the grains, already weakened by intergranular penetration of the copper-rich phase, by hot-working operations caused the grains to separate and surface tears ensued when the working tem-

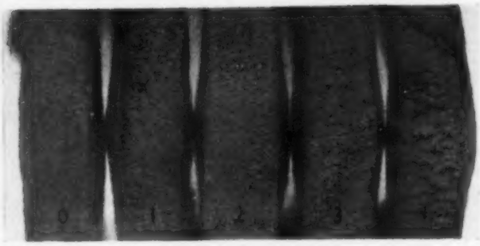


1 *Diagram of hot-bend test apparatus*

perature fell below 930°C. He concluded that such copper-containing steel should not be heated to above 1,040–1,070°C.

The Ingot Surface Defects Sub-Committee in 1950 reported[6] the results of bend test experiments carried out at 950°C. on mild steels containing 0–0·085% Sn, and 0·25–0·5% Cu. It was concluded that, with this range, variation of the copper content appeared to have a greater effect on hot shortness than did variation of the tin content.

A West of Scotland Iron and Steel Institute Symposium in 1950 on 'Residual Elements in Steel' reflected the importance of the influence of nickel and sulphur as contributory factors leading to surface discontinuities in copper-containing steels. W. A. Smith[7] reported that if nickel was under 0·15% and copper under 0·1% and the fuel was reasonably low in sulphur, there was little danger of the development of oxide roots. As nickel and copper increased to above 0·3% there was an increasing danger of rooting and a greater need for low sulphur fuel. With over 0·3% Ni and Cu or a total of 0·5% Ni + Cu, serious rooting developed whatever the atmosphere, within the limits of current commercial fuels. In 1952 Foster and Gilchrist[8] reported that the addition of nickel to copper-containing steels resulted in improved hot-working properties, while the addition of tin to copper or copper-nickel steels had the reverse effect. No attempt was made, however, to study the influence of different furnace atmospheres on these results. Buchholtz and Pusch,[9] using low-carbon steels, found that with unfavourable conditions of reheating in coke gas-fired furnaces and under high



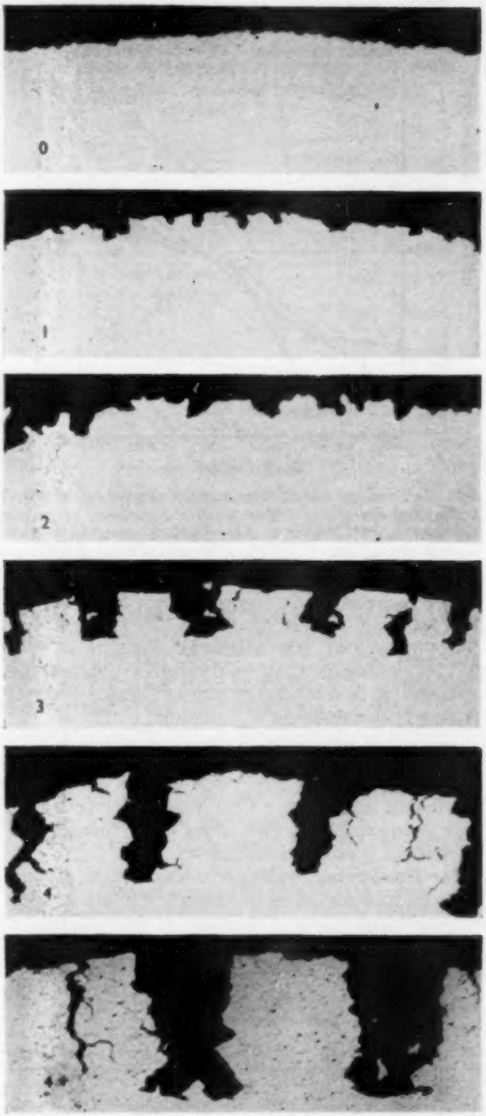
2 *Cracking code and surface appearance of hot-bend test bars (actual size)*

tensile stresses (in tube making), the critical contents of copper and nickel in the steels were about 0·15%.

A notable contribution to research on the significance of temperature on surface cracking of copper-containing steels was made by Born[10] in 1953. He investigated the influence of small copper contents and of the additional effect of tin simultaneously present, on the development of surface cracks in steel during hot working. Hot-bend tests were carried out between 850 and 1,200°C. on low-carbon steels with 0·2–2·0% Cu, which showed that copper contamination of the steel between 950 and 1,150°C. could lead to surface cracking. Born found a sudden decrease in the susceptibility to cracking at temperatures in the range 1,150–1,200°C. and considered this to be due to the extensive scaling of the surface preventing the concentration of a copper-rich phase.

It would be unwise to draw definite conclusions as to the effects of tin on the hot-working properties of steel in view of the extent of conflicting evidence in the literature. From some results[10, 11, 12, 13] it would seem that contents of less than 0·1% Sn can lead to poor forgeability, and yet others[14, 15, 16] have shown that amounts of the order of 0·2% Sn have not seriously affected the hot-working properties. However, there has been general agreement that the carbon content can influence the 'critical' tin limits—the higher the carbon content, the greater the harmful effect of tin on forgeability. But experimental evidence is lacking in the identification of a specific tin effect in steels of various carbon contents with such residuals as copper and nickel also present, and the influence of forging temperature has received little consideration.

In general, previous work[17] has shown that the presence of nickel in steel favours the formation of an adherent scale, and does not impair the hot-working properties. If copper is present in the steel, however, the Cu/Ni ratio may reach a critical value, above which hot shortness may be expected to occur during forging.[5, 10] The importance of furnace atmosphere has been stressed[3, 7, 9] with particular regard to the presence of sulphur, which



3 *Cracking code and actual crack dimensions of sectioned test bars, unetched* × 15

Crack dimensions (inches)

Code No.	0	1	2	3	4	4+
Depth	<0·009	0·009/0·014	0·014/0·020	0·020/0·030	>0·030	>0·060
Width	<0·010	0·010/0·020	0·020/0·030	0·030/0·040	>0·040	>0·070

may lead to unfavourable hot-working characteristics in steels containing nickel.

The first systematic investigation of the influence of sulphur in the furnace atmosphere and of the influence of residual metals in steel, interacting at various temperatures, was carried out by Born[1] in 1956. He reported the results of an attempt to distinguish between surface crack formation caused by residual copper and tin in plain carbon steels, and surface damage effected by the presence of sulphur in the furnace atmosphere. His theory was that a plain carbon steel could be prone to grain boundary cracking in the forging temperature range because of the effect of copper or tin impurities (the low-melting-point enriched-copper alloy causing a breakdown in the cohesion of grains), but not because of the effect of sulphur in the furnace gases. Born even claimed that sulphur had a favourable effect on hot workability, because by reason of its great affinity for copper it would react to form copper-sulphide preventing the concentration of a dangerous copper-rich phase in the steel surface, the result being that not only high-residual copper steels but also copper alloy-steels would lose their crack sensitivities. The authors' present work has, to a certain extent, substantiated this observation but with some reservations.

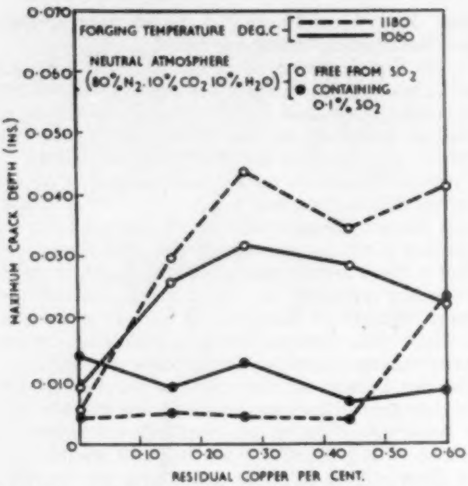
Experimental procedure

Steel specimen bars (4 by ¾ by ¾ in.) were heated for periods of 6 h. at 1,150°C. in a 'neutral' atmosphere (80% N_2, 10% CO_2, 10% H_2O) with additions of 4% free oxygen and/or sulphur dioxide (0·1–0·15%). After this soaking treatment, the furnace temperature was adjusted so that after removing a specimen from the furnace a hot-bend test could be carried out at 1,060°C. or 1,180°C.* after a time of 2–3 sec. When the bars had cooled, the degree of surface cracking was noted and selected bars were sectioned and prepared for metallographic examination. Crack and structural features were recorded and the relationship between crack depth, residuals in the steel, furnace atmosphere and forging† temperature shown graphically.

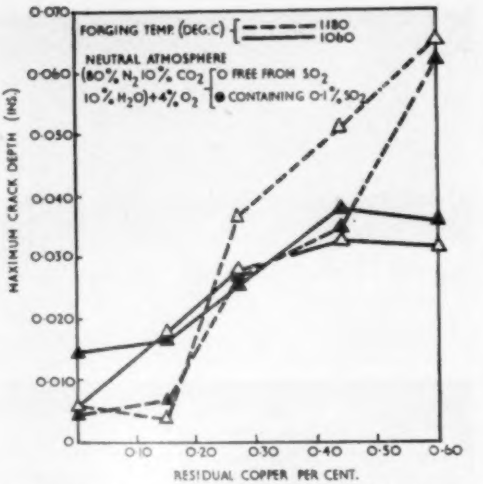
(*a*) *Material used.* The work was carried out with 11 mild steels of analyses as in Table I made in a

*These temperatures were selected to represent a convenient range around 1,094°C., the peritectic temperature in the Fe/Cu system.

†The terms 'forging' and 'bending' are synonymous in this paper.



4(*a*) *Relationship between max. crack depth—% copper—atmosphere for plain carbon steels. Specimens forged at 1,060 or 1,180°C. after soaking for 6 h. at 1,150°C. in a neutral atmosphere, with and without SO_2*



4(*b*) *Relationship between max. crack depth—% copper—atmosphere for plain carbon steels. Specimens forged at 1,060 or 1,180°C. after soaking for 6 h. at 1,150°C. in a neutral atmosphere + 4% O_2, with and without SO_2*

5-lb.-H.F.-induction furnace. The 8 by 1½ in. dia. ingots were rolled and forged to approximately ½-in.sq. sections before shaping to 4 by ⅜ by ⅜ in. for hot-bend test bars.

(*b*) *Scaling apparatus.* The furnace and synthetic gas supply unit was in principle the same as that used by Preece, Richardson and Cobb.[18] The necessary modifications are described elsewhere.[19]

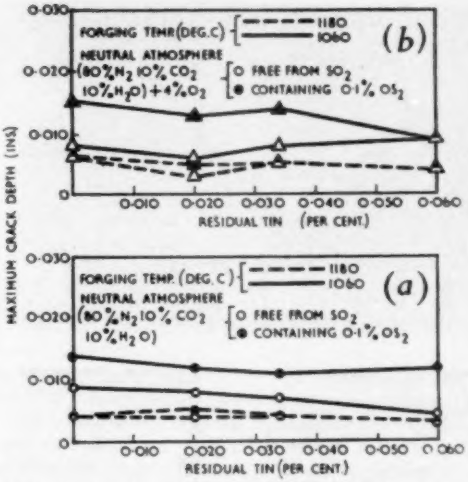
The standard furnace atmosphere used was 80% N_2, 10% CO_2, 10% H_2O, described as a 'neutral' atmosphere, *i.e.* one obtained by the complete combustion of the fuel. Such an atmosphere represents approximately the products of complete combustion of a fuel oil, bituminous coal or producer gas with the theoretical amount of air for complete combustion. In order to simulate an oxidizing atmosphere, 4% free oxygen was added to the above neutral atmosphere now being equivalent to burning the fuel with 25% excess air. Sulphur dioxide was added in amounts of 0·1–0·15%, approximating to the burnt producer-gas atmosphere of a typical reheating furnace obtained from a coal containing 2% sulphur.

In view of the nature of the investigation a linear gas flow-rate of 2 ft./min. (volume flow-rate approximately 1 litre/min.) for each 6 h. soaking treatment was used. This was found to give a sufficiently turbulent flow of gas in the furnace tube to produce a uniform scaling.

(*c*) *Hot-bending technique.* Two series of tests were carried out so as to examine the influence of forging temperature. One series of bars was bent at 1,060°C. and the other at 1,180°C. Bending to an angle of 160° over a ⅛-in. radius was accomplished

TABLE I *Analyses of experimental steels*

Cast	Elements (%)									
	C	Mn	Si	S	P	Ni	Cr	Mo	Cu	Sn
A	0·17	0·39	0·22	0·019	0·007	—	—	—	Trace	0·005
B	0·18	0·37	0·25	0·016	0·007	—	—	—	0·15	0·005
C	0·18	0·33	0·14	0·019	0·006	—	—	—	0·27	0·005
D	0·18	0·46	0·19	0·015	0·005	—	—	—	0·44	0·006
E	0·18	0·38	0·25	0·015	0·009	—	—	—	0·60	0·005
F	0·15	0·38	0·20	0·014	0·008	—	—	—	Trace	0·020
G	0·15	0·25	0·22	0·014	0·007	—	—	—	Trace	0·034
H	0·18	0·20	0·19	0·015	0·006	—	—	—	Trace	0·060
L	0·41	0·38	0·23	0·016	0·017	Trace	0·010	—	0·19	0·021
M	0·30	0·36	0·34	0·016	0·017	Trace	0·005	—	0·18	0·058
N	0·25	0·50	0·21	0·015	0·015	0·15	—	—	0·20	0·023



5 Relationship between max. crack depth—% tin—atmosphere for plain carbon steels. Specimens forged at 1,060 or 1,180°C. after soaking for 6 h. at 1,150°C. in: (a) neutral atmosphere, with and without SO_2, (b) neutral atmosphere + 4% O_2 with and without SO_2

by placing the specimen across two radiused uprights and applying a pivoted arm across the centre of the upper face (fig. 1). An average time for withdrawing a bar from the furnace to completing the bending operation was 2–3 sec., during which time the temperature of the surface, measured by means of a disappearing-filament pyrometer, fell by 20–30°C. Hence the furnace temperature was adjusted to 20°C. above the required forging temperature to allow for this cooling effect.

(*d*) *Classification of cracking tendency*. On examining the bent bars for surface cracking, it was convenient to classify the relative cracking tendencies in accordance with a numerical code illustrated in figs. 2 and 3.

Experimental results

The separate and combined effects of residual copper, tin and nickel in steels soaked at 1,150°C. in various furnace atmospheres and forged at 1,060 and 1,180°C. are shown in figs. 4 and 5, and Table II.

One of the interesting features of these tests was that the residual-free steel and the tin containing steels showed a comparatively low cracking tendency for all atmospheres and at both forging temperatures (fig. 5). This suggested that the freedom from cracking was a result of the absence of copper in these steels rather than a specific effect of furnace atmosphere. It also compared favourably with previous views[6, 14, 20] that tin contents up to 0·1% Sn did not appear to seriously affect the hot-working properties of steel.

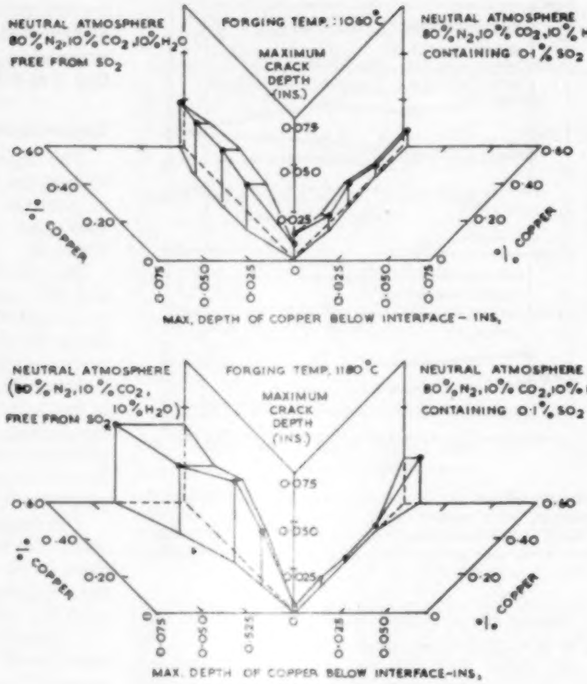
The copper-containing steels, however, presented quite different results (figs. 4(*a*), (*b*)). In general, these steels showed a marked cracking tendency at both forging temperatures and for all atmospheres with one important exception.

Copper-containing steels treated in a neutral atmosphere containing sulphur dioxide showed a practically negligible cracking tendency. The steel containing 0·6% Cu, an exaggerated residual content, was exceptional after treatment in this atmosphere in that a marked cracking tendency was found when forging at 1,180°C. The formation of copper sulphide as suggested by Born,[1] is thought to have contributed to this low cracking tendency in the majority of the steels, and it is suspected that

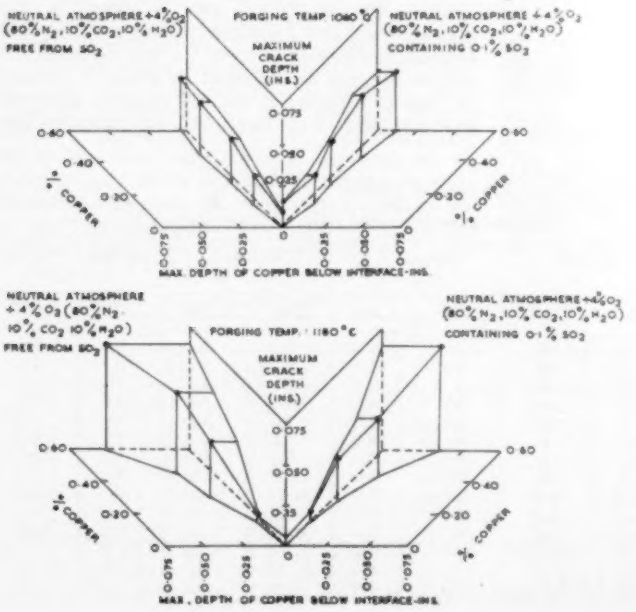
TABLE II *Cracking tendencies* of plain carbon steels*
Soaking treatment: 6 h. at 1,150°C. Forging temperatures: 1,060 and 1,180°C.

Cast	Residuals			Furnace atmosphere and forging temperature (°C.)							
	Cu %	Sn %	Ni %	Neutral		Neutral + 0·1% SO_2		Neutral + 4% O_2		Neutral + 4% O_2 + 0·1% SO_2	
				1,060	1,180	1,060	1,180	1,060	1,180	1,060	1,180
A	Trace	0·005	nil	1	0	2	0	1	0	1	0
B	0·15	0·005	nil	4	4	1	0	2	1	2	1
C	0·27	0·005	nil	4	4+	1	0	4	4+	1†	4
D	0·44	0·006	nil	4	4+	0	0	4	4+	4	4+
E	0·60	0·005	nil	4	4+	1	4	4	4+	4	4+
F	Trace	0·020	nil	1	0	2	0	0	0	2	0
G	Trace	0·034	nil	0	0	1	0	0	0	1	0
H	Trace	0·060	nil	0	0	2	0	0	0	1	0
L	0·19	0·021	Trace	n.d.	n.d.	1	0	n.d.	n.d.	0	n.d.
M	0·18	0·058	Trace	n.d.	n.d.	1	0	n.d.	n.d.	1	1
N	0·20	0·023	0·15	n.d.	n.d.	3	3	n.d.	n.d.	1	n.d.

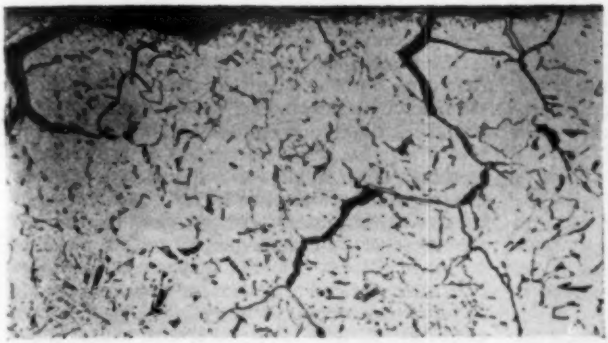
n.d. = not determined
*Numerical cracking code illustrated in figs. 2 and 3
†Macro appearance irregular (max. crack depth = 0·026 in. = Code 3)



6 *Relationship between max. crack depth —% copper—depth of copper below interface for plain carbon steels. Specimens forged at 1,060 or 1,180°C. after soaking for 6 h. at 1,150°C. in a neutral atmosphere, with and without SO_2*

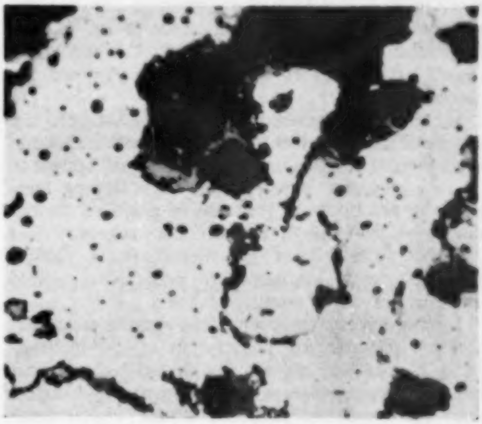


7 *Relationship between max. crack depth —% copper—depth of copper below interface for plain carbon steels. Specimens forged at 1,060 or 1,180°C. after soaking for 6 h. at 1,150°C. in a neutral atmosphere + 4% O_2, with and without SO_2*



8 LEFT *Penetration of copper-rich phase below metal/scale interface. Specimen from Steel E (0·6% Cu) soaked for 6 h. at 1,150°C. in a neutral atmosphere + 4% free O_2 + 0·1% SO_2 and forged at 1,180°C., etched in 2% Nital* × 100

9 BELOW *Complex sulphide-eutectics in specimen from Steel N (0·15% Ni, 0·20% Cu, 0·023% Sn) soaked for 6 h. at 1,150°C. in a neutral atmosphere + 0·1% SO_2 and forged at 1,180°C., unetched* × 500



the exceptionally high 0·6% Cu prevented the complete conversion of copper to copper-sulphide.

The relationship between residual copper, crack depth and depth of copper below the metal/scale interface for various furnace atmospheres is shown in figs. 6 and 7. For a typical reheating furnace atmosphere containing free oxygen and sulphur dioxide, as residual copper is increased in the steel, the subsequent depth of visible copper and crack depth also increase (fig. 7). This was especially apparent in those specimens which had been forged at 1,180°C., at which temperature the copper-rich phases would have been molten (fig. 8).

The remaining experiments were studies of the combined effects of residuals. From the results of other workers[8, 13, 21] it was anticipated that the addition of tin to copper-containing steel would tend to increase its susceptibility to cracking during hot working. For atmospheres containing sulphur dioxide, the results showed that the steel containing 0·18% Cu, 0·058% Sn was slightly more susceptible to cracking than the steel containing 0·19% Cu, 0·021% Sn, when forged at 1,060°C., though in each case the degree of cracking was not particularly great. This suggests the possibility that the important factor in the combined effect of copper + tin on hot shortness is the order of the copper content and not that of the tin (up to 0·1% Sn).

It was believed from other reports[3, 7] that residual nickel might lead to surface cracking after the steels had been soaked in sulphur-containing atmospheres and subsequently hot worked, in view of the nature of the complex sulphides formed (fig. 9). Although material was limited, the results of the small number of tests carried out supported this view.

The effect of 0·15% Ni in a steel containing 0·20% Cu, 0·02% Sn was found to increase the cracking tendency when the steel had been heated in a neutral atmosphere containing sulphur dioxide. The presence of free oxygen in this atmosphere tended to nullify the effect of sulphur (previously shown by Preece *et al.*[22]), and the cracking tendency of the steel was only slight.

During the examination of hot-bend test sections, the variation in depth of decarburization between different steels was found to be only slight. The maximum depth recorded was 0·029 in.

Discussion

When a steel containing residual metals is scaled and hot worked and the phenomenon known as ' hot shortness ' is encountered, it is often regarded as a measure of the residual impurity in the steel. Hot shortness, however, may arise from the presence of any intergranular molten films or brittle phases which possess an inferior cohesive strength, too low to withstand tensile stresses during deformation. The presence of such discontinuities is not necessarily a measure of residual impurity. It may be related to such variables as the temperature and atmosphere of the reheating furnace that determine the nature and extent of the

scaling process, which, in turn, will favour or prevent the harmful concentrations of residuals at the metal/scale interface.

The present work has clearly shown the importance of forging temperature and furnace atmosphere in controlling the effects of certain residuals in steel.

Influence of forging temperature. The choice of two forging temperatures, *viz.* 1,060 and 1,180°C., enabled an examination to be made of the effect on hot shortness of a molten copper-rich phase, since above 1,094°C. (the peritectic temperature of the Fe/Cu system) the copper-rich α-solid solution is liquid.

In general, for most of the copper-free steels the degree of cracking was more marked at 1,060 than at 1,180°C. Although the difference between the temperatures was only of the order of 120°C. it is considered that the greater plasticity of the steels forged at the higher temperature minimized the cracking tendency.

In the copper-containing steels, however, the degree of cracking was found to be quite marked at both forging temperatures. There would appear to be two opposing factors. The high forging temperature favours: (i) The ease of plastic deformation with less risk of intergranular rupture; and (ii) the formation of low-melting-point phases, which through intergranular penetration would increase the risk of rupture.

It would appear that when the soaking treatment favours intergranular penetration of low-melting-point copper-rich phases (fig. 10) the consequent loss of intergranular cohesion has a greater effect than the improved plasticity at the higher temperature and cracking tendency is increased.

Influence of furnace atmosphere. Considering scaling as a diffusion-controlled mechanism, it would be expected that the nature of the scale formed and the constitution of the metal/scale interface would in some measure govern the manner and extent of subsequent diffusion processes. The importance of furnace atmosphere lies in its influence on such physical and chemical properties of the scale as porosity, thickness, adherence, oxygen/sulphur potential, and residuals concentration.

The most significant feature of the influence of furnace atmosphere on cracking tendency appears to have been the effect of the presence or absence of sulphur.

In general, it was found that copper-free steels showed the greatest cracking tendencies after treatment in sulphur-containing atmospheres. The presence of sulphur in a furnace atmosphere has been shown to increase the extent of scaling,[22] as a result of the greater diffusion of ions in molten or semi-molten sulphide-eutectics. The formation and penetration of such low-melting-point phases would undoubtedly decrease intergranular cohesion and increase cracking tendency.

The copper-containing steels, however, were found to have a practically negligible cracking tendency after treatment in the neutral atmosphere containing sulphur dioxide, with only one exception (the 0·6% Cu steel, referred to in the previous section). The affinity of sulphur for copper is greater than that for iron at 1,150°C. and the change in free-energy during the reaction favours the formation of cuprous sulphide, which melts at 1,100°C. Copper sulphide (characteristically blue in colour) appeared to be confined to the metal/scale interface in association with FeO/FeS eutectic and, unlike the metallic copper-rich solid solution, did not penetrate along grain boundaries into the steel, and consequently did not seriously disturb intergranular cohesion.

In the absence of sulphur, the scaling process of oxidation by water vapour, carbon dioxide and free-oxygen appeared to have exerted little influence on cracking tendency in all steels, except those containing only copper as residual.

During the scaling of steels containing residual copper, the preferential oxidation of iron may lead to concentrations of copper at the metal/scale interface, since copper is more noble than iron. Such zones may become molten during soaking and copper-rich phases would probably extend and penetrate along the grain boundaries causing disruptive effects on hot working. This was found in steels containing *greater than* 0·2% Cu; in general, as the copper content increased, there was a tendency for the depth of copper visible below the

10 *Intergranular penetration of copper-rich phase. Specimen from Steel E (0·6% Cu) soaked for 6 h. at 1,150°C. in a neutral atmosphere + 4% free O_2 and forged at 1,180°C., etched in 2% Nital* × 250

surface and for cracking tendency to increase, with few exceptions. The controlling factors in all these instances appeared to be the rate and extent of oxidation.

When free oxygen was present in the furnace atmosphere, steels containing *less than* 0·2% Cu showed only a slight cracking tendency, whereas after treatment in a neutral atmosphere cracking was quite marked. One reason for this behaviour is probably that, because the oxidizing potential of the neutral atmosphere was low, compared with that containing free-oxygen, the diffusion and concentration of copper would be taking place over a shallow subscale zone, favouring copper-enrichment of the scale/metal interface. In the free-oxygen-containing atmosphere, scaling occurred rapidly; the rate of removal of iron was greater than the rate of diffusion and concentration of copper at the interface and the enrichment necessary to promote hot shortness was not attained.

Conclusions

(1) For copper-free steels, the greatest cracking tendencies were found after soaking in sulphur-containing atmospheres and forging at 1,060°C. The least cracking tendencies were found after soaking in sulphur-free atmospheres and forging at 1,180°C.

(2) For steels containing greater than 0·2% Cu a marked cracking tendency was shown after soaking in all atmospheres, except the neutral atmosphere containing sulphur dioxide. For this atmosphere, cracking tendency was practically negligible. The steel containing 0·6% Cu, however, was exceptional after treatment in this atmosphere, showing a marked degree of cracking when forged at 1,180°C.

(3) The steel containing 0·15% Cu showed a high cracking tendency after soaking in the neutral atmosphere, but a low cracking tendency for the other atmospheres.

(4) Residual tin (up to 0·060% Sn) appeared to have no significant effect on cracking tendency. In all tests the degree of cracking in these steels was very slight.

(5) The influence of tin in a steel containing 0·2% Cu tended to slightly increase the cracking tendency when present in amounts of 0·058% Sn, during forging at 1,060°C. When forging was carried out at 1,180°C., tin appeared to be without effect.

(6) The influence of 0·15% Ni in a steel containing 0·2% Cu and 0·02% Sn was to increase the degree of cracking after soaking in a neutral atmosphere containing sulphur dioxide.

Acknowledgments

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New aspects of the electron theory of metals

ARRANGED by the Metal Physics Committee of the Institute of Metals, an educational session on '*New aspects of the electron theory of metals*' was held in the Hoare Memorial Hall, Church House, Great Smith Street, London, S.W.1, last month.

Metallurgists are familiar with the basic ideas of the electron theory of metals, as laid down in the period 1920-40, and with the application of these ideas to the understanding of the structures and compositions of certain alloy phases, *e.g.* electron-compounds. The extension of this work to alloys of transitional and other more complex metals has proved less fruitful, however, and there are now doubts about whether one should continue trying to understand this wider range of alloys by more intensely applying the same ideas, or whether the present difficulties indicate some basic weakness in that approach in which case an entirely new approach may be needed.

The dilemma has been sharpened by the intense questioning of the fundamental theory and by the new points of view that have appeared in recent years. The difference between metals and insulators is now thought to depend on the ionizability of atoms rather than on the filling of Brillouin zones. Experiments have proved that the Fermi surface, which is not supposed in the old theory to touch the Brillouin zone boundary until the limit of the alpha phase is reached in copper alloys, in fact already touches it in pure copper; this appears to strike at the whole basis of the electron theory of alloys. New ideas have emerged in recent years about the state of valence electrons round alloy atoms in metals, about the behaviour of the free electrons as an 'oscillating plasma,' about the electronic structure of transition metals, and about the nature of valence bonds in solids.

It is thus a very timely moment for metallurgists to ask what are the changes now taking place in the basic theory, what new features are likely to emerge, how much is likely to remain of the old theory, and in what directions should one attempt to go forward now to gain a better understanding of alloying behaviour.

Tungsten

Development of metal lamp filaments

WHEN just 50 years ago Coolidge patented his process for producing tungsten of good workability and high density, he ensured not only a source of superior electrical contacts and X-ray targets, but success after years of struggle in drawing an intractable metal into fine wire for lamp filaments. The metallurgist and all interested in metal forming benefited from the first decade of this century when first osmium filaments, then tantalum, and finally tungsten proved the answer to a search for filament materials. After Nernst had tried refractory substances, and after even silicon and boron were experimented with, the year 1909 brought success with Coolidge working pure tungsten in the same year that the Siemens and Halske company in Germany had patented a method involving alloying with nickel, the nickel being removed by heating *in vacuo* to a high temperature.

To mention Siemens-Halske brings to mind the painstaking efforts of that pioneer in metal working, Werner von Bolton, a research worker who changed the history of tantalum by developing it in preference to niobium. Tantalum lost much of its importance where filaments were concerned, yet fine tantalum wires for radio and in surgery assumed prominence as a result. In contrast niobium has only recently received full attention in industry as a result of Von Bolton's preference for tantalum.

Early lamp filaments

Lamp filaments produced from retractable metals thus form an absorbing chapter in metallurgy, one crowded into a decade of intense efforts to render such metals ductile. They came as a third phase in the history of electric lighting and extended greatly our knowledge of metal treatment. The first type of electric lamp was that of Nernst; the first, that is, apart from the well-known carbon filaments of Edison and Swan (or of Göbel, too, although this pioneer failed to take out patent rights). Nernst was a professor of Göttingen who used thin rods of refractory metal oxides as source, such oxides becoming electrical conductors at the high temperatures used. It was a first success in following up an idea demonstrated in Welsbach's gas-mantle of refractory oxides, a success which stimulated others to try kaolin, oxides of titanium, zirconium, calcium and magnesium—all of which were soon abandoned when the carbon filament lamp banished all competitors.

A first demonstration of fine metal filaments as rival to carbon filaments came with Welsbach investigating the possible application of the platinum metals in this field. Iridium and osmium were to come into prominence for the first time since their discovery by Smithson Tennant, that Yorkshire chemist who was ever out riding and leaving his assistant Wollaston to work on his problems. It was Tennant himself who found a black metal residue left from crude platinum, however, a residue found to contain two brittle metals of the platinum family, metals he named 'iridium' since its salts had varied colours, and 'osmium' because this metal had an oxide with an objectionable odour.

Iridium and osmium

Iridium is a harder and more brittle metal than platinum, one which today cannot be cold rolled but only worked hot when it is very pure. The metal is drawn to wire using dry soap as lubricant, diamond or tungsten carbide dies, and requiring high-temperature annealing at intervals. As for osmium, even today it has not been successfully worked, although both metals alloyed in 'osmiridium' find use for tipping fountain pen nibs, for balance bearings, and for bearings in electrical instruments.

When Welsbach worked on these two metals, osmium was regarded as infusible and could not be drawn into wire, being known only as powder or 'sponge.' With osmium having a m. pt. of 2,700°C. and iridium one of 2,454°C., Welsbach was obviously unable to succeed in any direct working of the two metal powders; hence he adopted the 'squirting' technique in which the metal powder was made to a paste with a cellulose binder, then squirted through a die, and the resulting filament sintered at a high temperature to fuse the individual particles of metal. After removing the binding agent by volatizing it, a porous brittle filament was obtained for coiling and fixing to platinum lead-in wires.

This squirting technique of 60 years ago succeeded sufficiently in the case of osmium to enable the marketing of metal filament lamps. Improvements were made up to 1902 when the osmium lamp was one of the few types known on

any scale, in spite of the fairly high cost. The brittleness of osmium filaments resulted in a fragile lamp, the filament also having to be long owing to the low electrical resistance of osmium. Although a further disadvantage was that a maximum voltage of 110 had to be stipulated, the osmium filament proved more economical than carbon and stimulated the search for other metals as filaments.

Tantalum

Rather more than 50 years ago the first tantalum wire began to prove far more practical than osmium or iridium in the production of filaments. Tantalum is seen today as a first-rate choice as a malleable and ductile metal of high durability, one which would have come to stay but for tungsten at long last rendered workable by powder metallurgy. That pioneer in filament-making, Werner von Bolton, in conjunction with O. Feuerlein, had worked through a number of metals like vanadium and niobium before deciding to give full attention to tantalum as the most practicable metal. Moissan had fused tantalum in his electric furnace, yet the Siemens and Halske research workers found that his technique did not yield pure tantalum.

In 1903-04 the two German workers had refined tantalum and took out patents, so that by 1905 tantalum filaments were on the European market. The Siemens-Halske firm acquired a monopoly with control of the world's supply at that period; hence they became sole producers and licensed firms to assemble lamps using their tantalum filaments.

In the United States the G.E.C. and the National Electric Lamp Co. acquired rights to manufacture tantalum lamps with a life of 1,000 h. and with more durability than osmium lamps. Yet low resistivity meant long filaments as with osmium, a drawback offset by the superior tantalum filaments (superior to tungsten) in resistance to shock and vibration.

Tantalum working became developed to high efficiency in America in the hands of Dr. Balke of the Fansteel Corporation after he produced the metal from a rich ore supply from the Pilbarra desert of Western Australia. The metal was found to be very malleable and ductile when annealed, and could be easily worked cold and coiled for use as filament. The tantalum lamp still survived after tungsten came in, for special applications such as railroad lamps which had to withstand severe vibration. Direct current for the supply had to be used since a.c. causes crystallization of tantalum and therefore embittlement. In the production of tantalum fine wires, nowadays for radio valves, surgical sutures and gauze, it is found that tools and guides of aluminium bronze are invaluable in order to avoid galling or scoring of the metal.

Before leaving the work of Werner von Bolton, mention may be made to his success in preparing the first pure niobium regulus by the aluminothermy process followed by subsequent purification by repeated melting in a vacuum electric furnace. Niobium as sister element to tantalum was also ideal for filaments, yet the specimen prepared by Von Bolton remained the only pure sample in the world for over 20 years.

Tungsten

Tungsten, at one time 'the metal which cannot be melted since the crucible melts first,' was the eventual answer in this quest for metal filaments. Several years before Coolidge developed the modern technique, the metal had attracted attention as a powder adopted in the squirting process and as a coating element for covering a carbon or platinum filament. T. D. Bottome in the United States applied for a patent specifying tungsten plus carbon filaments in which the metal was claimed to improve the hardness of the carbon. Bottome also gave molybdenum as alternative to add to carbon, while in Europe experiments of the Westinghouse company included studies of coating carbon or platinum with tungsten, osmium, molybdenum or chromium. By 1898 Kellner in Vienna was using cellulose binding agents plus tungsten powder for heating *in vacuo* to produce filaments in which the carbon was graphitized.

Also prominent were Just and Hanaman of the Vienna Technical High School, who used an oxychloride of tungsten as vapour in efforts to deposit tungsten on carbon. These two workers in British Patent 23,899 went on to use the squirting process with finely-divided tungsten plus an organic binder forced through dies, this being followed by heating in an inert gas to remove the binder. Two years before Coolidge changed all such processes, the squirting technique had been much improved. The metal powder plus starch or dextrin were passed through diamond dies, the final filaments being wound on cards for drying and then cut into 'hairpins' before heating in the inert gas. After mounting each hairpin in clips it was raised to a bright red heat in a hydrogen atmosphere by electrical heating, the process yielding a sintered filament which was brittle as expected.

Even colloidal tungsten was tried in the search for filaments, while tungsten carbide was the material when a carbon core was used, removal of the inner carbon in steam at a high temperature giving filaments of tubular type.

Just and Hanaman put tungsten lamps on the market in 1906, although such filaments made were of 'non-ductile' tungsten and fragile. With a life of 800 h., but with good emissivity and usable with both a.c. or d.c., the first tungsten

lamps were an indication of the superiority of the metal once the problem of rendering it ductile had been solved. The Welsbach company in Austria was also working on the non-ductile filament, while Von Bolton was forging ahead with ductile metals with patents mentioning titanium, zirconium and other metals for drawing into filaments from sintered rods.

Ductile metals

By striking an arc between a tungsten rod and a tungsten pellet in a graphite crucible in a hydrogen atmosphere, the Siemens and Halske concern prepared some fused tungsten though not as a commercial proposition. Then in 1909 they specified in German Patent 223,885 their nickel alloying process for rendering tungsten ductile, just as in early platinum history a number of alloying methods were tried out.

In the Siemens-Halske process tungsten powder with from 6–10% nickel as oxide was pressed and sintered in hydrogen at 1,575°C. to yield small ingots. These were rolled to 1 mm. dia. at 350°C. and drawn cold with frequent annealing at 1,500–1,600°. Ductile wire as fine as 0·03 mm. dia. resulted, the nickel being removed at 1,500°C. *in vacuo*.

In this same year Coolidge brought the ductile tungsten filament to perfection in his classic patent of 1909 which covered the pressing, sintering, swaging and drawing operations. Coolidge had been trying a process involving an amalgam for making non-ductile tungsten; but, being dissatisfied, he and his fellow countryman Fink went on to produce the ductile metal. In 1908 they had succeeded in producing fine molybdenum wire by hammering, rolling and drawing while hot, but then found that molybdenum and tungsten differed from other metals in that they could be worked best below annealing temperatures—a point missed by the painstaking Von Bolton.

The metal powder in this General Electric Co.'s process is hydraulically pressed into bars, these being heated at 3,300°C. in a hydrogen atmosphere to cohere. Ten thousand hammer blows/min. are imparted to the tungsten rods at 1,500°C. at the start in a swaging machine which includes a split die rotated round the axis of the tungsten rod, the outer ends of the spinning die sections striking rollers mounted in a ring around the die and thus being driven back against the tungsten. Such dies are of high-speed hardened steel or of a heat-resisting alloy. After reducing the diameter of the rod to 0·05 in., further working is done in wire-drawing dies, first of the carbide type and then of diamond. It is no idle boast that the greatest triumph of the metallurgist was his production of ductile tungsten.

BOOKS

Metallurgical thermochemistry

By Kubaschewski and Evans. Third edition, Pergamon Press Ltd., London, 1959. Pp. 426. £3 3*s*. net.

THE APPEARANCE of the third edition of Kubaschewski and Evans now well-known work on thermochemistry is sufficient evidence of the general quality of the book and the reception that the previous editions has received.

No great changes have been made in this edition. A few alterations have been made to matters of detail in the text, the tables of thermochemical data have been brought up to date and two more examples of the application of the thermochemical approach have been added. Both examples are concerned with problems in metallurgical research—the purification of iron at the N.P.L. and an estimation of the solubility of alumina in nickel.

In their preface to the first edition the authors took pains to point out that thermochemistry is now fashionable in metallurgical circles and issued a caution that chemical reactions were generally subject to overriding kinetic considerations. Within this pertinent caution lies the reason for the contrast between the interest and activity which the subject inspired in the research laboratories and the relative lack of success which the works metallurgist has found when he has attempted to use the thermochemical technique to established works processes. However, the constant striving to improve the accuracy of thermochemical data and to extend their scope will gradually enable the technique to be of more and more use provided its inherent limitations are borne in mind.

The new edition will be welcomed by all research workers as a reference book. Works metallurgists, especially of the older generation, should study the examples of problems to which the method can be applied to refresh themselves both of its utility and its limitations.

A. D. HOPKINS

The physical metallurgy of rolling

By F. H. Scott. Arthur H. Stockwell Ltd., Ilfracombe, N. Devon, 1959. 10*s*. 6*d*.

WITHIN THE span of less than 100 small pages the author of this monograph attempts to give an account of the physical metallurgist's approach to rolling phenomena which is 'not too difficult to be understood by interested people from all walks of life where elementary technology is an everyday matter,' laudable sentiments having a somewhat Victorian missionary ring. The subjects dealt with include: deformation and metal physics, polychrystal [*sic*] deformation in rolling, the physical rolling, mechanical theory of rolling (friction hill) and the theory of rolling for apprentices. Unfortunately in his attempt to enlighten the common man of metallurgy the treatment of the subjects has become superficial, vague and sometimes irrelevant. For example, no clear distinction is ever made between hot and cold rolling; in the middle of the chapter on failure in rolling is a section on corrosion fatigue. No detailed references are given beyond a quite inadequate bibliography. The layout, style and figures one would expect to find in a struggling parish magazine.

Although Dr. Scott's general approach to the subject might form a basis for a larger textbook on rolling for a more sophisticated reader than he has attempted to reach, your reviewer can recommend this book for no one except aspiring technical authors as an awful warning. Extensive revision will be needed before this work can be considered for inclusion in any technical library.

A. D. HOPKINS

Spark machining symposium

Practical aspects of cavity sinking

G. H. C. RHODES

This article is the fourth of a series on spark machining. It forms part of the symposium held late last year at Birmingham by the NADFS in collaboration with METAL TREATMENT. *The remaining papers, together with the author's synopsis and discussion, will appear in this journal monthly. Mr. Rhodes, Wickman Ltd., discusses the practical aspects of producing die cavities by the spark-machining method. He compares the relative advantages of various methods of electrode manufacture and electrode materials, methods of setting and clamping, and finally the erosion sequence*

THE SCOPE OF FORGING and similar die manufacture by the spark-machining process has been greatly increased by the recent development of faster-cutting spark-machining generators, and the availability of larger capacity machines.

For some time the process could not compete economically with conventional three-dimensional copying machines except on the smallest of cavities and the general practice was to consider only the normal hand-finishing operation on die cavities to be a proposition for spark machining.

Many of the limitations of the process for forging die manufacture have now been removed. Spark machining can not only now be applied successfully to the manufacture of new die cavities, but in addition it offers many advantages for subsequent re-sinking operations, bearing in mind that the need to anneal the die before re-machining is dispensed with. Die blocks, 28 in. by 16 in. by 15 in., can be handled, and can be roughed out and finished more economically by spark machining, subject to the important condition that an economical method of producing electrodes can be adopted. Electrodes for simple, circular, rectangular type cavities are not a problem since these are simple and cheap to manufacture by conventional methods.

In discussing the practical aspects of producing die cavities by this method it must be understood that the economy of spark machining depends upon practical and economic electrode manufacture and application and the selection of the most suitable electrode material.

Electrode manufacture

Various methods of manufacture have been investigated all with the main object of low manufacturing costs. The method chosen must be also reliable enough to produce electrodes of consistent shape and tolerance with the minimum variation. If this condition is not maintained, excessive spark-machining times and difficulties in re-setting successive electrodes will be experienced. It is also probable that incorrect profiles will be produced.

The processes investigated so far are (*a*) Precision casting; (*b*) metal spraying; (*c*) heavy plating; (*d*) hot forging; (*e*) hot forging with cold setting operation; (*f*) cold pressing; and (*g*) conventional machining (including segmentation using simply shaped pieces).

(a) *Precision casting*. Electrodes produced by the 'lost wax' or Shaw process have been proved unsuitable. Surface porosity and blow-holes are very evident, with the result that the electrode surface does not erode away uniformly but breaks down quickly forming unwanted pockets and contours.

Electrodes produced by this method also vary from one to another incurring setting and machining difficulties.

(b) *Metal spraying*. This method requires a model either in wood or metal from which a mould is made usually in plaster or similar material. A heavy deposit of copper up to $\frac{1}{2}$ in. thick is sprayed into the plaster mould, with setting plugs or plates set in before spraying for setting and clamping.

The resultant form is usually very good. The structure of the material has a crystalline appearance but the grain size is small enough to prevent quick and uneven breakdown during spark machining.

Although this system provides a good constant electrode form, the present cost of manufacture is very high; experimental 10 h.p. con rod electrodes costing approximately £5 each.

(c) *Heavy plating*. This technique is similar to the spraying process. A model of the electrode form is prepared from which an Araldite mould is prepared. The prepared mould is then placed in a salt bath and a thickness of up to 0·200 in. is plated on and around the form.

The resultant electrode has excellent qualities, form, accuracy, and consistency of manufacture being first class, but once again the cost of manufacture is too high for the method to be employed economically. The cost of one electrode is greater at present than one produced by the spraying technique. A location and clamping platform can be plated on to the top surface of the mould. Any subsequent trimming and machining operation required on the platform can be done before removing the electrode from the Araldite mould block.

(d) *Hot forging*. This is an economical method of manufacturing electrodes. They are stamped out hot from a half-die, using a flat anvil fitted with dowel pegs to form the location platform.

The chief consideration with this method is the different shrinkage allowance between steel and copper. It is recommended that the method be applied mainly to long production runs, where regular die replacement and re-sinking is required. A die, specially cut to stamp out electrodes of the required size, would be produced. Several hundreds of electrodes could then be produced at one setting.

(e) *Hot forging with cold-setting operation*. Where the expense of a special die is not permissible, but a die already exists of the required form, it is possible to hot stamp the electrodes, anneal them, replace in the die and cold set them to the exact form of the die. A series of electrodes of known size can then be produced. With a size datum the electrode can be reduced uniformly to allow for the required spark gap, using an acid etch.

In cases where it is not economical to manufacture a new die by spark machining, this method can be used to produce electrodes, from the conventionally cut die, for subsequent re-sinking operations.

Up to date, it has been established that electrode production by the hot, cold-setting, or the cold-pressing methods has proved to be the most satisfactory and economical.

(f) *Cold pressing or hobbing*. This has proved to be a successful method for producing accurate and cheap electrodes. Its limitation is the size of electrode it can produce.

Tests have been carried out on a 2,000-ton hobbing press, and the maximum average size considered is 12–13 sq. in. projected area. The sized copper billet should be in the fully-annealed condition prior to pressing. With deep forms it may be necessary to anneal the partly-formed billet.

Experiments are continuing to increase the scope of cold pressing.

(g) *Conventional machining*. This method generally proves too costly. The contoured forms required necessitate that they be produced on three-dimensional copying equipment.

Where the form required can be produced by straightforward machining operations, however, cost is usually economical. In certain cases die cavities have been successfully eroded, using several uniformly shaped segments, used separately or together on a master plate.

Electrode material

Brass. As compared with copper, brass is slower cutting on the roughing ranges, but is comparable on the finishing ranges. Its wear rate is higher than copper, and thus more electrodes per cavity will be required. The inability to cold-work brass restricts the number of methods that can be used for electrode manufacture.

Its main application is for the manufacture and re-sinking of hot brass stamping dies. The electrode can be a half or a complete stamping, depending upon the location means available.

Aluminium and zinc-based alloys. The erosion qualities of these materials are poor in comparison to copper and brass. They have slower cutting rates and higher wastage values, with the exception of aluminium on the roughing ranges.

Aluminium is applicable for die-casting moulds where components from previous dies can be used as the electrodes. The low cost of such electrodes would offset the greater number of electrodes required and longer erosion time.

The zinc-based alloys or Mazac materials can also be employed where components from a previously cut die exist. Electrodes from this material can also be produced by the 'offhand' casting technique, using an existing or specially prepared mould. A titanite or similar hard plaster or plastic mould, taken from a model of the electrode, can be used.

Acid reducing for smaller electrode size

The problem of providing a smaller size electrode for the roughing operation than that used on the finishing has been brought to a simple and effective basis. Any one series of electrodes will be manu-

factured to a common size, usually the finishing size. Uniform surface reduction is done by an etching operation, using an acid solution. The electrode must be thoroughly degreased and the appropriate area immersed in the solution. It should be agitated slightly to prevent any effervescence adhering to any part of the electrode and thus restricting corrosion.

Periodically, the electrode can be removed, washed in water and the amount of reduction checked. Metal will be removed evenly with the exception of sharp corners which will tend to erode away faster.

If the electrode material is brass or copper, a nitric acid solution is the etching medium. A caustic soda solution is used for reducing aluminium.

The rate of removal will depend upon the solution strength and the temperature of the electrode. If the electrode is pre-heated the action will be more vigorous. Information on these conditions can be obtained from standard data.

Electrode flushing for efficient cutting

Removal of swarf from the spark gaps between electrode and workpiece is important to maintain the highest cutting efficiency. If the swarf becomes trapped and clogs the spark-gap area, cutting becomes erratic and sometimes stationary until the electrode is retracted and swarf brushed away, thus incurring frequent inspection on the part of the operator.

This condition appears mainly on the finishing operation where the spark gap and spark explosion is small and restricts the swarf clearance. It also prevails with cavity sinking on the coarse cutting ranges where, by nature of the blind and enclosed form, the normally efficient swarf removal by the high spark explosion and large gap is nullified. In both cases assistance has to be provided to remove the swarf. It is done by drilling small diameter holes through the electrode from the back platform to the affected areas. A flow of clean paraffin is then passed through these holes to flush the swarf out of the spark gap. Excessive pressures should not be used, otherwise a pressurized cushion of paraffin will form between the electrode and die which will tend to counterbalance the servo system load.

Auxiliary piping which can be adapted for this purpose is usually provided on the machine tool. A multi-branch small-bore copper pipe system fed from a common pipe is frequently employed, the various branches feeding paraffin to the holes drilled in the electrode.

This method of electrode flushing can be employed on both roughing and finishing electrodes. Any slight pips of metal left on the workpiece through the presence of flushing holes in the electrode can be removed by a simple bench operation.

Location and setting

As previously mentioned, it is important that each electrode of any series be prepared with a common datum location. The location is usually provided on the back platform, and can be milled faces, dowel holes, or scribed lines. In certain cases it is possible to produce these location points in the same operation as forming the shape of the electrode. A suitable method is to fit dowel pegs to the anvil being used to forge the electrode. The dowel holes produced in the platform become the datum points.

It must be stated that it is not always necessary to produce a half forging with a rear platform. In certain cases where the contours of the required forging carries uniform bosses and platforms which can be readily used for location, the electrode can be produced to the complete forging form. This refers primarily where die sets of the exact or similar form to be eroded already exist.

A horizontal faceplate fitted to the spindle of the machine tool, and fitted with suitable location facilities, is probably the most positive means for carrying and locating electrodes for die-sinking work.

This type of fixing can be used to locate the position on the die block and consequently relate the electrode accurately to the die block. Once the electrode holder has been positioned to the die block, the machine tool head is locked in that position, throughout the spark-machining operation. This type of electrode holder can be made to suit a range of different electrode forms.

Preparation of die block

Setting points must be provided on each half-die in order to reference the electrode or electrode holder to the correct position on the die. Similar or identical means to that used to reference the electrode to its holder should be used. Two axes of known position and taken at right angles to each other through the plan of the forging will be adopted as datum lines from which any reference point can be taken.

Through these reference points the corresponding axes on the electrode can be positioned to those on the die block. These reference points can be the outside edges of the die block or scribed lines accurately marked out. Either of these positions can be set to coincide with the outside edges of the electrode holder, machined to known dimensions from the two datum axes.

Another method is to employ two dowel-hole positions, one on each axis at known positions. The electrode holder will be fitted with dowel pegs

which will be aligned to correspondingly positioned dowel holes in the die block, and subsequently in the electrode platform.

The spark-machining operation

Having decided upon the die to be spark-machined, the number of electrodes and their type has to be decided, together with suitable location and clamping means to reference the electrode to the die block. The number will depend upon the size and contour system of the impression. The decision to pre-machine any part of the die will also affect the number to be applied.

Although fast roughing speeds can now be achieved by spark machining, the possibility of introducing a roughing operation, prior to any hardening or toughening, by conventional machining, should not be ignored. Where part of or even the bulk of the cavity to be sunk can be machined by a simple and cheap milling, drilling or turning operation, this should be considered, since spark machining will not compete economically with straightforward machining operations.

No positive rule can be laid down as to how many electrodes will be required; this decision will rely mainly upon the experience of the operator in charge of the equipment. The number of electrodes will be split up into roughing and finishing sets; occasionally a semi-roughing or semi-finishing electrode may be required on an intermediate range. The roughing electrodes will then be reduced in acid to allow for the greater spark gap.

The swarf removal will have to be checked, and the appropriate flushing hole drilled through the electrode where required, if necessary. This may be required on both roughing and finishing electrodes. The type and number of electrodes, method of location, cutting speeds, and finishes required must be thoroughly examined before any spark machining is undertaken.

In effect, the operator having completed his set-up, set the controls and depth stop, will only be required to change electrodes and restart the machine without any unnecessary re-aligning, thus a minimum of skilled supervision will be necessary during the machining operation.

If the electrode form contains any slender projection when the roughing stage is started it is preferable to commence erosion on an intermediate range until the main body of the electrode comes into contact. This will prevent excessive wear taking place on these projections, and probably conserve the number of electrodes used. The importance of maximum roughing cannot be overemphasized. The finishing speeds are so many times slower than the roughing ranges that the minimum amount of material should be left for finishing, otherwise excessive time will be taken on the final stages. Applying an extra roughing electrode should be considered rather than leaving too much material for finishing. This is most important if the best economics of spark machining are to be obtained.

The function of the finishing electrode is to refine the die surface and size the cavity. Very little wear takes place on the finishing electrode and it is common practice to use it for roughing operations on other dies. To determine at what point the cavity is complete, various inspection means can be used. A good guide can be taken by checking the amount of wear on the final electrode. This will give a good indication of the cavity size.

Some spark-erosion machines are fitted with high-speed, small-amplitude spindle or table vibration. These systems are brought into use during the finishing cuts and assist the swarf removal from the spark area by creating a pumping action between the electrode and workpiece which keeps the swarf agitated and on the move.

AUTHOR'S SYNOPSIS

Mr. G. H. C. Rhodes, delivering the synopsis of his paper, said that the problem of cavity sinking by spark machining could be broken down into three headings: (1) electrodes, (2) methods of setting and clamping the electrodes, and (3) the erosion sequence. The aspect of cavity sinking dealt with the erosion part only, but electrodes must be included, because they threw a very valuable economical aspect on the whole process.

In his paper he had outlined various ways of manufacturing electrodes specifically for the forging die industries. These were methods which his company had investigated, which other companies had investigated on their own behalf and which were used as a basis for computation and consideration when applying work to spark machining. An electrode for a forging die was usually one-half of a complete forging, generally produced with a back platform. This was not a hard-and-fast rule. A complete forging could be employed, with bosses and flat platforms to be used for clamping and location.

The location and setting of electrodes was the crux of the matter. Unless care was taken to manufacture an electrode of correct size, form, and uniformity, a good form would not be obtained. Further, an economic price on the die would not be obtained. Without this precaution a company would be continuously having to make various adjustments to the die. The electrode must be made accurate and repetitive. This prerequisite must be accepted if spark machining was to be applied successfully.

Location problems

Dealing with location problems, Mr. Rhodes said there was a very readily-made position, namely, the back platform on the electrode. There had been various ways and means of accommodating this location, either through dowel holes, set edges or scribed lines. Each of these, dependent upon the accuracy to be held within the die, could be considered. The electrode then had to be referred to the die block. The die block was normally marked out. In certain circumstances the same procedure would be used. If the set edge of the electrode was being used the set edge of the die would be used from which to reference it.

These problems were not of spark machining. As had been mentioned by a previous lecturer, they were the problem of a production engineer. A spark-erosion machine would perform a certain operation, namely, cut a three-dimensional aperture without further control once the set-up and location had been pre-set. That was the only function the spark machine would carry out. It was for the production engineer to provide an accurate tool for producing the cavity. There was no easy way round this.

The ways and means of making electrodes and the intricacies of setting were obvious and normal machine-shop practice. The vital point was the accuracy of the electrode. Having dealt with one die in a certain way, one should not fall into the trap of thinking that all the other dies could be dealt with in the same way. It was essential to keep an open mind on the problem, and to be always investigating and trying to improve. Mr. Rhodes's company had learned this from bitter experience. It had been very useful, because they were able to go out to the people in the field and give them the information.

Mr. Rhodes emphasized that there must be co-operation. The engineers in the spark-machining society provided the machine tools for doing the work. They provided the tools to do blanking tools, moulds, dies and innumerable types of work, even production work. Therefore, they had a basic knowledge from which they could work. By applying this knowledge in the various channels they could assist the user. The user in turn must assist them.

DISCUSSION

Mr. Hobdale (Cutlery Research Council) congratulated Mr. Rhodes on his paper, which covered an aspect of spark machining only too often neglected in technical papers. Many of Mr. Rhodes's statements had confirmed Mr. Hobdale's findings on the practical methods necessary to obtain accurate results. His organization had carried out considerable work on the practical application of the process. In the cutlery trade, tool rooms were small and firms did not possess such machines as jig borers or accurate vertical milling machines which larger firms could use for electrode location techniques. Nor did they have large capacity presses available for cold pressing electrodes. In addition, a large variety of dies were produced in small quantities.

Mr. Rhodes's remarks on the methods of manufacturing electrodes were very interesting. The Cutlery Research Council had found that for normal cavity sinking, hot-forged cold-set electrodes made of copper gave excellent results. No doubt other delegates would be able to cite cases where other manufacturing methods had proved to be highly successful. It was, however, essential that the electrodes had stability. The flat-backed type were to be recommended for small or thin electrodes, and they would ease location problems.

Dealing with location, Mr. Hobdale said that Mr. Rhodes had stressed the need for accuracy, which he wholeheartedly endorsed. No matter what adjustments were provided on the machine, it was virtually impossible to locate electrodes in the same place without some form of pre-mounting technique. The scribed line method could give reasonably accurate results, but was entirely dependent on the machine operator's skill. Mr. Hobdale felt that this was bad. His Council had recently published a booklet entitled 'Electrode spark machining of forging dies,' which recommended the method of mounting electrodes using a jig and a master die. This method has proved very accurate and simple to apply. The master die could also be used for electrode manufacture to stop accumulated errors occurring over long periods of time.

The removal of swarf from the spark gap was of the utmost importance. The paraffin pressure also appeared to be critical. Mr. Hobdale asked if Mr. Rhodes had any figures on what the optimum pressures were. His experience had shown that pressures of 4–8 lb./sq. in., when used on small contoured cavities, gave increased cutting rates on finishing electrodes. In addition, arcing due to swarf accumulation was eliminated. Arcing could destroy a die in the finishing stage.

In conclusion Mr. Hobdale asked Mr. Rhodes whether he considered it a practical proposition for manufacturers to market suitable electrode-mounting jigs and mounting spigots as part of the equipment of the machine. He had in mind some form of universal jointed holder to which the electrodes could be attached by one or two screws without any machining on the back of the electrode.

Mr. Rhodes, replying, said that with regard to the paraffin clearance in a spark gap, he did not think that there were definite pressures to which

one could work. One type of work would warrant a heavier flow than another. By having an adjustment on the paraffin flow system, it was possible virtually to tune the flow to suit the correct conditions. By trying to put too much pressure through the spark gap, one could easily create virtually a pressurized cushion which the servo, that is the feeding system, would tend to bounce against and not break through. There were no definite pressures. It depended upon the spark gap, whether it was being used on a coarse feed where there was a large spark gap, thus enabling more paraffin to get through, or whether it was being used on a small or fine setting where there was a very fine gap and consequently a much smaller flow.

Mr. Hobdale's method of dealing with the holder problem was a good point. Mr. Rhodes's company as manufacturers went part way with Mr. Hobdale on that, dependent upon the unit. The plate to which Mr. Hobdale had referred was a common sort of datum point. By having a plate, either the set edge of the plate or the dowel system could be used to reference the electrode tool. Obviously for rigid purposes this would be well mounted directly on to the spindle of the machine tool rather than in another mounting, say a chuck or vice. It depended entirely on the work.

The suggestion for a holder was very good. It was the sort of suggestion for which his company was looking.

German research

Herr Dipl.-Ing. Zabel (Hanover Technical University) said that he thought that this was a suitable moment to report on the research concerning spark machining being carried out by the Forschungsstelle Gesenkschmieden of Professor Kienzle in Germany.

Copper and brass having proved to be electrode materials suitable in many applications, a method has to be found to manufacture electrodes economincally in these materials. Shapes of electrodes are rather complicated, especially in the drop-forging industry, and their production by mechanical forming would be a good solution. Accordingly, the Forschungsstelle was asked to investigate the possibilities of producing electrodes by mechanical forming.

Herr Zabel said that he could speak of results of two preliminary investigations only, as the main experiments had started only a short time ago and it was still too early to report the first results. In spite of this, he wished to present the university's whole plan and to hear criticisms and hints from the delegates. He was especially interested in their opinion, as there were several other methods of producing tool electrodes either already used or under discussion, namely, casting, sintering, heavy plating, etc.

The experiments planned would establish the behaviour of copper and brass during mechanical forming in different dies and under various conditions. After this it would be known for which forgings dies could be spark-machined with mechanically-formed electrodes. In addition, both the obtainable accuracy of the electrodes and the necessary power for forming would be determined. Velocity and temperature during forming, as well as lubricants, would be varied. Moreover, the air in the die was compressed on account of the good contact between copper and steel. This seemed to have an influence. As to the different die forms, practical shapes as represented by normal forgings would be chosen and also idealized ones, such as truncated cones and pyramids, hemispheres, etc., for which measuring methods were not so complicated. There was another reason for investigating the forming of electrodes in idealized forms, because many indications of how to design formable basic forms and surfaces for locating and clamping would be obtained. In any event, questions of locating and clamping should be dealt with carefully, because the solution of these problems was essential to the success of spark machining.

The programme had been started by investigating the possibilities of calculating the admissible strain of the dies used for forming electrodes, as several firms had complained of cracked and damaged dies. It was essential to distinguish between dies with flat impressions in which the stress might reach the yield stress and dies with deep impressions in which the stress must not exceed a certain fraction of the yield stress as they were strained similarly to a thick-wall tube with an internal pressure. The internal pressure in a thick-walled tube might rise to 60% of the yield stress at the most. The ratio of admissible internal pressure to the yield stress for thick-walled tubes depended upon the ratio Q of inside diameter to outside diameter.

In a case where the projection from a forming impression in the forming direction was not too complex in shape but of a cross-section roughly equivalent to a circle, an interference fit could be calculated for the forming die, as was possible with extrusion tools. The internal pressure in a ring with an interference fit could become substantially higher than in a simple ring.

Forming dies offered two additional difficulties during calculation compared with extrusion tools. They had a stiffening base and were strained in an axial direction by the flash which developed during forming. The axial strain led to noticeable lateral extension by which the outside ring would be overstressed. This overstressing could be avoided if

the initial tension of the interference fit was lowered by that amount which arose from lateral extrusion during working. So the approximately correct tension in the interfering faces would be achieved throughout the process. The influence of the base could be estimated by thinking of the forming die as being divided into a ring and a disc, for both of which the calculation was done separately. By this method the real case was located within limits.

For forging dies with impressions with a complexly shaped projection in forming direction so that no definite ratio Q of the diameters could be determined it was impossible to give useful initial tensions or allowable internal pressures.

The second group of experiments dealt with the possibility of reducing copper electrodes in size by scaling. The thickness of the removed copper layer was dependent on time and temperature of annealing.

It was remarkable that any thickness of layer could be removed by scaling without appearance of irregularities, which were unavoidable when etching more than 0·2 in. layers. The curves of Feitknecht were proved by the university's experiments in an electric furnace. To reduce the scaling time, the electrodes must be de-scaled by cooling in water periodically, as the scale layer grew less when it got thicker. In spite of these provisions, between three and ten times longer was taken than with etching for the same reduction in size, depending on the chosen conditions. This disadvantage could be compensated by annealing a greater number of electrodes at the same time, as careful movement required during etching was not necessary with annealing. The scale layer was practically independent of the pressure of oxygen. So the required reduction in size could exactly be achieved by controlling the time if the temperature indication of the furnace was calibrated carefully.

Dies for ploughshares

Mr. G. L. Cardwell (Ransomes, Sims & Jefferies Ltd.) said that he had recently divorced himself from the general run of the forging industry—motor cars and aeroplanes—and was now in the agricultural industry. His particular problem was the making of ploughshares. A ploughshare was of such a peculiar shape that he thought the electrode would have to cover the whole impression and the die face, probably using an electrode measuring about 20 by 15. As his company would make only six pairs of dies a year and could mill a pair of dies by conventional copy milling, taking about 120 hours plus making the moulds and the die sinking, did Mr. Rhodes think that it would be right for the company in a development scheme to include spark machining for such work as that?

Mr. Rhodes, replying, said that he had considered whether it would be possible to spark machine a ploughshare die and had formed the opinion that it was possible. Whether it was an economic proposition for Mr. Cardwell's company was another matter. Six pairs of dies had to be made per annum. Depending upon the time taken by spark machining and the installation of the unit, the critical consideration was whether the overall cost of spark machining compared with the present cost justified it, with the same recovery value of machine tools of, say, five or six years. With six pairs of dies there would be a month's working of the machine out of twelve months.

Mr. Cardwell said that he was thinking that perhaps his company might set up a Sparcatron machine with the large electrode and then put the operator on to another machine and return in a fortnight and say that the job was done.

Mr. Rhodes said that the idea was absolutely correct, although the fortnight might have to be a little extended. He thought that it was a proposition with spark machining. Whether Mr. Cardwell's company should install a spark machine for making six pairs of dies per annum was for the board of directors to decide, having considered the economics. Once having proved spark machining, it was hoped that as the other forgings tended to become a little enlarged the work would be gathered round the machine.

Moulds for plastics

Mr. N. E. Wall (Healy Mouldings Ltd.) discussed using spark machining for producing moulds for the plastics industry. Generally speaking, the mould life in that trade was fairly good. They were not troubled with replacements. Unless they had many impressions to make, they could not become too involved in making electrodes. It had been found that cavities which were difficult to produce by conventional methods required electrodes which were difficult to produce by conventional methods. In addition, the high surface finish required took a very long time on the machine. To some degree this cancelled out the advantages.

Mr. Rhodes said that the problem of electrode manufacture was that, whether it was a mould or a forging die which had to be made, an electrode had to be produced to spark machine it. How it was produced depended entirely on the economics of the job, whether it was cheaper to do it by profile milling, forging or casting. In the mould industry they did not have the facilities and necessity to forge. They were moulders. Therefore, invariably they had to resort to conventional machining for electrodes.

Mr. Rhodes agreed with Mr. Wall on the possibility of casting electrodes, but the quality of a cast

electrode was not very good. He thought that it was very poor for Mr. Wall's type of work. Various investigations were going on into sprayed metals and heavy plating, but unfortunately heavy plating was a very expensive process. In heavy plating one would make a master, probably a pattern maker or machine a master, one-off. That would be then sunk into an Araldite or plaster mould of a similar type. The plate would then be sprayed into that mould. If the economics of these processes could be studied and the cost brought down, they would prove very attractive for the plastic moulding industry. It would be necessary to make one master only, then take a plaster mould from it and then spray or heavy plate. Apart from that, Mr. Rhodes could give no other lead. He advised Mr. Wall to use his own judgment whether spark machining was the proposition, remembering that the various electrodes required would have to be milled or machined.

Turning to the surface finish problem, in practice, especially in the mould industry, people always insisted that they wanted the best finish possible. That was fair enough, but they would insist on going down to the very finest finish on the spark-erosion machine, which Mr. Rhodes considered to be something of a retrograde step. On the spark-erosion unit there were various settings provided, of which the finest was a very slow cutting medium. Mr. Rhodes would consider a slightly coarser finish a proposition. The definition, shape and size were in the die. It then became merely a surface-polishing operation to bring up the finish to one's own requirements. Where one had to polish, it was completely unnecessary to go for the finest finish a unit would provide. It was a waste of time when one had to polish afterwards. A spark-machined finish of a reasonably fine nature polished far more quickly than a conventionally machined surface.

Mr. Wall added that his company found that it wanted the finest finish a machine would give it, and that was where the time was taken. His company must have the finest finish to polish.

Mr. Rhodes said that he could not understand that. Obviously, he could refer only to the units he was used to handling. The cutting rate of a medium type fine finish was reasonably fast, much faster than a very fine finishing operation, and he would recommend it for mould work where polishing operations had to be done afterwards. The difference in surface structure between them was not tremendous. To take off 2 thou from the surface for this particular setting would be ample. It was not a metal removal operation Mr. Wall was doing. It was a surface polishing operation. He was not having to size and shape the die with a hand tool, he was merely polishing the surface.

Electrode casting

Mr. M. C. Vaughan (A. J. Vaughan & Co. (Mitre Works) Ltd.) asked two questions. First, both Mr. Rhodes and Mr. Adcock had dealt with the disadvantages inherent in the casting of electrodes. What comment had Mr. Rhodes to make on the suggestion that electrodes would be made by straight casting, followed by a cold pressing operation? Secondly, was there any beneficial effect on surface finish from the vapour blasting of the die cavity after spark erosion?

Mr. Rhodes said that the reason for the derogatory remarks which had been made about casting was as Mr. Adcock had stated in his lecture. They had found a porous problem. The surface looked good, but once they got below it they started forming unwanted contours. They would not be convinced until someone brought along to them a satisfactory casting on which they could rely.

With regard to casting and then a cold pressing operation, Mr. Rhodes said that he was not qualified to speak on the structures involved in the two different operations. From the casting he imagined that a very crystalline, coarse, grain-type structure would be obtained. Whether it would move, by either an annealing operation or some other means, to be cold pressed or cold hobbed he could not say definitely. Perhaps there was someone present who would give Mr. Vaughan the answer to that problem. It was a line of thought to be welcomed, because the suggestion of casting at a reasonably low cost and then cold forming would get over the original cost of electrodes. However, if cold forming was to be carried out after casting, why not cold form all the way through? Cold forming or cold hobbing, on the information at his disposal, was limited in its areas, for instance with a solid type of electrode round about 12 sq. in. was the maximum projected area. Mr. Rhodes said that his company had given thought to trying to extend cold hobbing or pressing, but could give no definite information. As regards casting and then cold hobbing, one might as well cold hob straight away.

Mr. Rhodes asked if anyone present would care to comment on Mr. Vaughan's suggestion of casting and then cold hobbing.

Mr. K. Applebee (Metropolitan Vickers Elec. Co.) said that some work his company had been doing recently on casting with a subsequent pressing operation might be of interest. It had been found that the use of zinc-tin alloys for electrodes produced quite good results. They were not quite so good as copper, brass or even Mazak alloys, but they were remarkably easy to form. The beauty of these alloys was that they had a very long freezing range. If they were cast into a metal master, which need not be very strong, they could

be pressed whilst they were still virtually in a semi-solid state, thus producing a remarkably good finish. The performance of the electrodes also seemed to be good. The idea originated in the United States, where they tended to think in terms of using five or six electrodes which were very easy to produce rather than trying to produce a really high quality electrode which was very often very expensive. The idea had not been studied sufficiently in the United Kingdom. The tendency was to try to produce an excellent electrode with rapid cutting properties and very low wear rates, whereas there might be something in the possibility of producing a cheaper electrode which could be easily formed and easily changed. It was very easy with zinc-tin alloys. His company had been trying an alloy which was almost 50% of each. All the location points could be formed, and there was virtually no machining, apart from drilling the oil holes. His company had successfully produced electrodes up to 3 ft. long by about 6 in. wide by this method.

Mr. Rhodes commented that it was an interesting point. He could not comment on the erosion properties of the zinc-tin alloy because he had never dealt with it as an electrode material.

Mr. Applebee's general comment about off-hand pouring was an excellent idea. With subsequent pressing it was even better. Mr. Rhodes's previous findings had been that off-hand pouring was the cause of the porosity of the white metal being poured. Further, some areas cooled more rapidly than others on this non-uniform type of section. This was not an overall picture. Good ones were produced with certain types of work, but it had not got those common qualities throughout the whole range of the type of work in which the company was interested.

Mr. R. Ing (Mallory Metallurgical Products Ltd.) asked Mr. Rhodes to be a little more specific on the surface finish values to which he had referred earlier. He asked for figures in C.L.A. micro-inches which Mr. Rhodes in his general experience had been employing for polishing on blind cavities.

Mr. Rhodes said that with blind cavities the surface finish would suffer due to the presence of swarf in the cutting zone. It was very difficult to remove swarf when machining a cavity. Doing through work—such as press tools and compacting dies—where the finish was critical on carbide, the best finish obtained by Mr. Rhodes's company had been 4–6 micro-inch R.M.S. That was on a through form. On a cavity there was a possibility, if it was adequately flushed and the swarf kept away, that the same value would be obtained. This was on carbide. On a steel it would be of the order of 8-10 micro-inch R.M.S. That would hold true on any clean surface. With cavities the main problem was removing swarf. Before the value of flushing was known and explored, it was known that the carbon collected between electrode and die and formed small hot spots or resistor pads and burnt small indents. That was one of the main reasons for going into the flushing problem on the fine settings.

Mr. R. A. Riley (Alfred Herbert Ltd.) asked what rate of metal removal Mr. Rhodes would expect to achieve with carbides to obtain those micro-inch finishes.

Mr. Rhodes regretted that, without reference to data, he could not say. He presumed that the question dealt primarily with a very fine setting where very fine finishes were obtained. He did not know the exact metal removal rate. They were never asked by industry the cubic metal removal rate of a finishing range. Industry was more interested in what they could blast at than what they could fine at. He would be glad to give the information if Mr. Riley contacted him later.

Mr. T. Martin (Garringtons Ltd.) asked if Mr. Rhodes could enlarge on the construction of electrodes by the copper graphite cement process. He had seen in a previous discourse that there was a method by which a 10% mixture of cement could be included with copper and graphite. Was it a dry mix with the copper in the powder form? Was it a method to be recommended? It seemed to be fairly quick with a damp mix subjected to 60 ton/sq. in. pressure. The presence of the cement in the mixture did away with the sintering operation, which possibly could occur on a simple copper graphite mixture.

Mr. Rhodes said that he was not qualified to answer that. His company had tried this as a material and found its properties. From the application point of view and the user's point of view it did not interest him. He asked Mr. Adcock to answer the specific question.

Mr. J. L. Adcock said that the copper was in the form of powder; it was a dry mix. In his paper he had said: 'The three constituents must be very thoroughly dry mixed to ensure even distribution and then brought to a paste-like consistency by the addition of water.'

Mr. Martin asked if it was fairly robust in structure, or was it likely to flake and cause bindings or trouble in the sparking operation?

Mr. Adcock said that it had to be chosen with some care, having due regard to the shape of electrode. This was a similar consideration to that applying to a sprayed coating, which he had mentioned earlier in the paper. He had stated that those electrodes were not particularly robust. A more delicate shape could be used if the power levels on application were kept down.

Mr. A. J. Lawrance (Kimber-Allen Ltd.) mentioned a method which his company had used, in the hope that it would assist some delegates. Many forging and stamping dies were made to produce parts which required die cavities of semi-circular cross-section, such as dies for valve bodies, Ts, elbows and other pipe fittings. For cavities of this type his company had developed a technique whereby the cavity, which might consist of several branches of semi-circular cross-section, was split into sections, each section comprising one axis of rotation. The electrodes were made by turning from bar to the correct form. Obviously, as several electrodes were required for each section if copy-turning equipment was available it was an advantage. The electrodes were then suspended in a special holder between centres. It was fairly simple to sink the centre line of the electrode down to the die face by using cut-away centres. His company used in addition a spring plunger to ensure adequate contact.

This method had a number of interesting advantages, the main one being that the whole surface of the electrode was used by occasionally rotating it a section of the circle as sparking proceeded or letting it sink to depth and then rotating it and sinking it again, and so on. In addition to using the whole surface and spreading the wear evenly over the entire surface, it generated a truly circular cavity and assisted the flushing of the cavity, which was often the difficulty for cavities of this shape.

Mr. J. A. Duncan (Westinghouse Brake & Signal Co.) asked if Mr. Rhodes had any experience of producing aluminium electrodes by the pressure plaster process. This appeared to be a process for producing quite sound aluminium castings of good surface finish and accuracy at a very cheap rate. It would be very suitable for firms not having all the facilities of the motor industry. Further, in connection with producing these electrodes, Mr. Duncan asked Mr. Applebee to state the composition of the zinc-tin alloy.

Mr. Rhodes said that his company had carried out this process on behalf of its customers. He had used electrodes made by this process. The controlling issue was whether the aluminium was to be used as an electrode material. It depended on which sphere of the industry a company was interested in. His company had tried it and had found it very successful. As with any form of pressure die casting, consistent results with the electrode had been obtained.

Aluminium was initially a fast-cutting electrode material on the heavy cutting ranges, but suffered in rate on the lower finishing ranges. However, as a die casting was so readily available and so cheap, the longer erosion time was offset by the initial low cost of the electrode. The issue at stake was the electrode material. The process for making it was excellent.

Mr. Applebee said that his company had tried various alloys of zinc-tin. It had found that 50% zinc and 50% tin by weight gave almost as good a result as any, and it tended to be easier to form than having a higher zinc content.

Mr. Applebee then referred to two-phase materials and asked for Mr. Rhodes's comments. From the work his company had done at Manchester it appeared that by using an electrode material which had two distinct phases—for example, copper graphite, which was a sintered material; 60-40 brass, which was a two-phase brass, and zinc-tin which he had mentioned, which was also a two-phase material—remarkably good results were obtained, both from a wear and a cutting point of view.

The work his company had done on metal spraying had shown a tremendous amount of promise. The metal removal rate obtained from sprayed brass was higher than anything they had been able to obtain from any other material. This was purely working on mild steel and one or two steel alloys. The ease with which an electrode could be formed with the metal-spraying technique lent itself to economic electrode manufacture. Care must be taken not to waste much material, because it was rather expensive.

Mr. Applebee asked for Mr. Rhodes's comments on two-phase materials. Further, a metal-sprayed electrode consisted of a very large number of voids. The lower melting point constituent was not there in the case of sprayed copper. Did Mr. Rhodes think that there was anything in the theory that the lower melting point constituent virtually dropped out of the electrode, doing no work and leaving a structure which lent itself to spark machining? One could also quote pure graphite in rod form, which was an excellent electrode, but it was very difficult to form into any shape. It was very porous.

Mr. Rhodes said that metallurgically he could not comment on two-phase alloys. He was primarily interested in what an electrode would do. He could not comment on what happened when the electrode material was being used, which material came out and which material worked.

His company was very interested in metal spraying. It looked as if it could open up another field of electrode manufacture. At present its cost was a little prohibitive considering that five or six electrodes might be used for eroding one-half of a die, even considering that those electrodes might be used as finishers for successive dies. His company's one-off electrode, in shape like a con rod, had cost £5. Its erosion qualities were very good.

continued on page 162

Press forming aluminium alloys

THE SHAPING of aluminium alloy components by hand press or power press, in which sheet metal is pressed into a given shape, is differentiated from both deep drawing—where the metal is drawn into shape—and from forming by the drop stamp—in which the metal is hammered into shape.

In press forming work, two dies, consisting essentially of a male and female copy of the contours of the shape to be produced, are used. The male die, which is a reproduction of the inside contour of the article standing in relief, is fixed to the press ram, which rises and falls at a steady speed—in contrast to the drop stamp; while the female die, which is recessed into the contour of the outside shape of the article, is fixed to the press bed. When a suitable blank is located over the bottom die it is formed or pressed to shape by one stroke of the top die.

In such a press operation from a blank of pre-calculated dimensions, the tools produce a shape in concordance with the clearance between the forming punch—or male die—and the forming die—or female die—with little or no alteration in the metal thickness and axial dimensions of the finished component when compared with the original blank.

Importance of surface finish of dies

The construction and surface finish of the dies can contribute largely to the success or otherwise of pressing operations. Since aluminium alloys are relatively soft and therefore tend to adhere to the punch during the downward forming stroke, it is essential that tools should be made to precision limits and given a high polish to remove all markings introduced in the toolmaking operation and leave a perfectly smooth surface over which the metal will flow during forming.

Poor surface finish on the dies results in difficulty in stripping the formed article from the press, introduces scratching owing to metal drag and often causes distorted or broken punch tools.

For long production runs, tool steel, hardened to give maximum resistance to wear, is normally used. The female die, which is subject to the sliding action of the sheet being formed, is lubricated. A suitable lubricant is medium-grade machine oil diluted to a satisfactory consistency with paraffin or, for heavy-gauge material, tallow applied as a coat.

The formed part is removed from the die by ejectors, which may be either manually or mechanically operated. In order to avoid marking or distortion it is important that the knockout should cover as large an area of the base of the part as possible, as shown in fig. 1.

Problems of springback

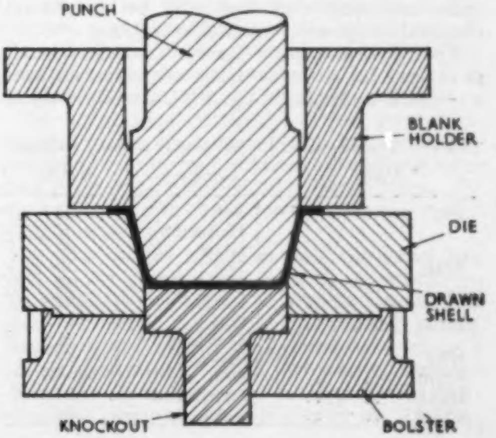
A major difficulty experienced in the press forming of B.S.S.1470 H14 or H15 type alloys is the springback of the metal; that is, the article when withdrawn from the die does not retain the true contour and right-angle sides in a dished cup, for example, but may spring several degrees from the designed location.

It is impossible to maintain a constant degree of springback in any pressing made in one forming operation owing to variations in the nature of the surface of the sheet metal and in the conditions of lubrication of the blank-holders, while in addition the elastic limit of the metal is affected by both the cold working resulting from roller-levelling to remove distortion and by the age-hardening process.

Springback difficulties, however, may often be overcome in the following manner. The pressing is taken to almost full depth under conditions of easy flow of metal through the blank-holders. The blank-holder pressure is then readjusted to restrict any further slip and the punch taken to the bottom of the stroke.

In this way the amount of stretching necessary to minimize springback is obtained, together with easy flow through the blank-holders in the initial

1 *Typical tool layout for press-forming operations*



stages of the draw necessary to prevent splitting of the metal. Springback may be reduced still further if the pressing is solution heat-treated immediately before the final forming operation.

The relative formability of springback can also be calculated from the stress/strain curve. The following examples show how the method may be used to find the springback of various aluminium alloys relative to a standard sheet.

In bending a sheet of given thickness over a given radius a definite strain results. The stresses corresponding to this strain are obtained from the stress/strain curve. Using annealed sheet to H14 or H15 as the basis of comparison, the ratios of springback for sheet to H14 or H15 in the heat-treated condition and H10 both in the heat-treated and work-hardened conditions, should be approximately:

$$\frac{\text{H10 (heat-treated)}}{\text{H14 or H15 (annealed)}} \quad \frac{35{,}000}{24{,}000} : 1 \cdot 5$$

$$\frac{\text{H10 (work-hardened)}}{\text{H14 or H15 (annealed)}} \quad \frac{46{,}000}{24{,}000} : 1 \cdot 9$$

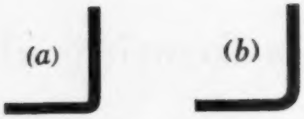
$$\frac{\text{H14 or H15 (heat-treated)}}{\text{H14 or H15 (annealed)}} \quad \frac{64{,}000}{24{,}000} : 2 \cdot 7$$

These figures compare favourably with the ratios of springback determined by experiment.

Permissible bend radius

In tool design the radius to be given the edge of the punch and the corresponding corners of the forming die in relation to the metal to be pressed is a factor of major consideration. The minimum permissible radii vary with the type of operation to be carried out, the alloy being formed, the type of press used and often they may be determined accurately only under working conditions.

The fact that an angle formed with a sharp bend, as in fig. 2 (*a*), is not as strong as one formed with a rounded corner, as in fig. 2 (*b*), should be borne



2 (*a*) *angle too sharp*, (*b*) *radiused corner makes for easier working and stronger bends*

in mind. It is customary to refer to bend radii in terms of inside radii.

It is important in all forming operations that the material should conform closely to the profile of the tool; otherwise there is a danger of forming to a more obtuse radius than that intended.

Table I is a guide to the minimum permissible radii for 90° bends in relation to blank thickness for aluminium alloys. The general characteristics desirable in aluminium and its alloys to be subjected to bending are similar to those for pressing and deep drawing. Alloys suitable for bending are B.S.S.1470-77:1955: 1, 1A, 1B, 1C, N3, N4, N5, N6, N7, H9, H20, H30, H14, HC14, H15 and HC15. H11, H12 and H18 are not normally bent.

Practical aspects of cavity sinking

concluded from page 160

Mr. R. A. Riley (Alfred Herbert Ltd.) asked if Mr. Rhodes had any experience in machining graphite by spark erosion, using an air gap. The normal fluids could not be used.

Mr. Rhodes said that Mr. Riley was correct in saying that dielectrics were the problem in that process. Air was a very poor dielectric for spark machining. There was a tendency for arcing to take place. Carbon could be machined only on very low spark intensities, otherwise it would tend to shatter and split. The only efficient medium under which it could be done was distilled water. However, the trouble with distilled water was that, with a percentage of contamination of 1%, a very high increase in resistivity resulted, causing the corrosive factor to rise.

TABLE I *Radii required for 90° bend in terms of thickness*

Alloy	Condition	V.P.N.	26 s.w.g.	20 s.w.g.	16 s.w.g.	12 s.w.g.	10 s.w.g.
Slc.	Soft	22	0	0	0	0	0
	Half-hard	35	0	0	0	0	0
	Hard	42	½	½	½	½	½
NS3	Soft	30	0	0	0	0	0
	Half-hard	44	0	0	0	0	0–1
	Hard	54	1–1½	1–1½	1–1½	1–1½	1–2
NS4	Soft	48	0	0	0	0	0–1
	Half-hard	78	½	½–1	½–1	1–1½	1–1½
NS7	Soft	87	0	0	0	0–½	0–½
HS10	Soft	45–65	0	0	0	0	0–½
HS14	Sol. treated	120	1½	1½	2	2	2
HC14	,, ,,	120	1½	1½	2	2	2

Mr. S. Johnson (left) being installed as president by the immediate past president, Mr. J. H. Swain

annual general meeting, 1960

National Association of Drop Forgers and Stampers

THE FORTY-FIRST annual general meeting of the National Association of Drop Forgers and Stampers was held at the Botanical Gardens, Edgbaston, Birmingham, on the first of last month with Mr. J. H. Swain, president, in the chair. The meeting was attended by 120 persons representing 52 members and associate members of the Association.

It is the usual procedure of the NADFS that the presidents hold office for a period not exceeding two years, and Mr. Swain pointed out that his period of office was now terminating. After the formal proceedings, Mr. Swain installed his successor, Mr. S. Johnson, director, Daniel Doncaster & Sons Ltd., as president of the NADFS for 1960. He referred to Mr. Johnson's long service to the Association, as a member of the old Executive Committee in 1943, and since 1945 on the Governing Council.

In a short presidential address, Mr. Johnson said that it was the destiny of the NADFS to operate between steel suppliers and the motor vehicle builders. Both these industries have powerful trade organizations so who could doubt that the NADFS must also be strongly organized to negotiate and work with them.

These two great industries kept the public well informed of the large sums of money which they had spent and were spending to increase output and to effect economies, but it was not so generally recognized that the drop-forging industry had also spent many millions of pounds in recent years in re-equipment, mechanization, and improving working conditions.

The Association was organized to look after the affairs of the industry and to promote the supply of the highest quality drop forgings at the lowest economic price. All too often in the past, lowest price had been the sole factor deciding the placing of orders, but he was satisfied that a change had taken, and was still taking, place in this respect. Customers were recognizing that first cost was not necessarily the all-important factor in purchasing, but quality engineers and other experts were beginning to feed through more and more to the purchasing agents information on the advantages of a high-quality product, dimensionally and physically, and the economies to be gained if supplies were available at the time requested.

He hoped these tendencies would grow with ultimate benefit to customers and drop forgers as new developments and techniques could only proceed if money was provided to finance them. In the end it was a loss to all concerned to sell or buy below the economic price.

Another matter which he was convinced was vital to the industry was research, to which the Technical Committee and Governing Council had given so much consideration, resulting in the formation of a Sponsoring Committee to set up a research association. Whilst he was president he would do all in his power to support the Independent Committee presided over by Mr. Golcher,

to sponsor the setting up of the new research project.

Mr. Johnson also referred briefly to the question of steel supplies. It was extremely important that the Association should regularly make known its needs and the extent to which suppliers might be falling short in meeting them.

He was greatly interested by what Mr. Swain had said in his report about co-operation on problems of mutual interest with drop-forging associations on the Continent. This extension of activities he considered to be of the utmost importance in the future development of trade association work. He looked forward with pleasure to participating in these conferences during his period of office.

President's report

In his annual report of the work of the Governing Council during 1959, Mr. Swain said that a new full member had joined during the year under review and one new overseas Associate Member from Denmark. He had, however, to report the resignation of a South African Associate.

Mr. Swain then spoke of an important development in connection with international drop forging. Members would be aware of the British Delegation to the Third International Convention of Drop Forgers and Stampers which was organized by the French Drop Forging Association and held in Paris last May. He took this opportunity of thanking the French for their hospitality and for the wonderful manner in which they organized this important gathering.

During the Business Sessions it had become apparent that there were a number of topics of common interest to all drop forgers, and it had been decided that an exchange of knowledge and experience would be beneficial to all concerned.

As a preliminary step, arrangements had been made for occasional meetings to be held between the presidents and senior officials of the French, German and United Kingdom Associations with the object of getting some unified views on these subjects and perhaps either circulating a report, or presenting one at the new International Convention which is to be held in Great Britain in 1962. Discussions were held a few weeks ago on this matter at a meeting of Directors in London at which Mr. Todd was host, and which was attended by Mr. Killing, Director of the German Association, and Mr. Novar representing the French Drop Forging Association.

The vacancy created in Group 'A' by the election to the presidency of Mr. S. Johnson had been filled by Mr. J. H. Hemingway, who had been selected to take his place on the Governing Council.

It was with regret that Mr. Swain had to report that the Technical Officer, Mr. G. W. Jackson, was leaving at the end of the month to take up an appointment in Australia. During the two and a half years that Mr. Jackson had been with the Association he had done much valuable work, particularly in connection with the proposed Research Organization. The comprehensive report which he produced on this subject had been of great value. On behalf of the NADFS he wished Mr. Jackson success and happiness in his new venture.

On the subject of the Research Organization he wished to emphasize the fact that it was to be an autonomous body quite independent of the Trade Association in respect of membership, management and finance. Nevertheless, they looked forward to unanimous support from the members of the Trade Association as the sponsoring body, and were confident that the scheme would also attract a good measure of support from non-member drop forgers and other firms who had a stake in the industry.

The question of scientific and technical research had been under consideration by the Council and Committee for many years. It had at last been decided to go forward with a worth-while project, and having in mind the fact that facilities had been arranged at the Sheffield Laboratories of BISRA he felt sure that they had every prospect of launching the scheme with success.

A year ago the trading position of the industry was far from happy, being in the middle of quite a sharp trade recession. From the beginning of 1959 there had been a modest increase in orders which had, in recent months, developed into a flood. Some members were having to increase their capacity in order to meet the rising demands made by the motor industry. The output of cars, commercial vehicles and tractors in 1958 reached the record figure of 1,500,000, in 1959 the total was over 1,720,000 vehicles and the ambitious plans that were being made indicated further large annual increases over the next five years.

The resurgence in demand had already brought with it some complications in steel supplies. Once again they were coming up against limited allocations insufficient to meet the needs, and members were complaining about shortages of billets both carbon and alloy, and some large users were having to resort to importation at high prices. This situation was under constant review by the Commercial Committee and a detailed report had been submitted to the Iron and Steel Board.

Mr. Swain then spoke of the work which the Labour and Welfare Committee had been doing, under the chairmanship of Mr. M. C. Vaughan, in relation to the training of new entrants matters in connection with the safety and welfare of employees. He had noted with particular interest the attention

which this committee was paying to the question of noise. He felt sure that close attention would have to be given to this subject in the future. A Royal Commission had recently been appointed to go into the question of noise generally and they would be ready to co-operate with this body in its complicated investigations.

Mr. Swain said that this was the last occasion upon which he would be speaking as president and he wished to thank all his colleagues on the Governing Council, his wide circle of friends in the industry, for the courtesy, loyalty and kindness which they had shown during his period of office. He also wished to thank the Director and his staff for the help they had given throughout the period; their vigorous activity and well-informed guidance had been invaluable.

Technical and Production Committee

Reports of the work of the committees were then presented by the chairmen of the committees. Mr. W. E. Golcher began by presenting a brief review of the work of the Technical Committee during the last 12 months. He spoke of the importance of the Research Organization and said that he believed that it had wide and fruitful field of activity in front of it, and that it would be very well placed at the Sheffield Laboratories of BISRA.

The Spring Lectures had been held last year as was the Droitwich Convention in November. An important additional feature of the year had been the holding of a one-day Symposium on 'Spark Machining' for die-sinking purposes. This Symposium had been addressed by a most distinguished body of speakers and by a wide representation of the engineering industry who were also interested in one form or another of die sinking. The papers which had been read at the Conference and the discussion had been printed and distributed to all attending. It was gratifying that many additional copies of the papers had been called for and were still in demand. They formed a valuable assembly of the present knowledge of the application of spark machining to die making.

Report of the Commercial Committee

In the course of his report on the work of the Commercial Committee Mr. J. F. Insch said that since the early autumn of 1959 there has been an enormous improvement in the trading position, as a result of which the outputs of drop forgings in September and December were records.

The improvement in business conditions had brought with it the usual attendant difficulties in connection with steel supplies and particularly in connection with carbon steel billets. They had dealt with the matter in two ways, firstly, by reporting likely shortages in 1960 to the Iron and Steel Board, and secondly, by applying to the Board of Trade for a relaxation in import duties. Arising out of the report on shortages to the Iron and Steel Board a meeting was held to discuss this matter further with representatives of the Iron and Steel Board and Federation.

With regard to the application for a relaxation in import duties on carbon steel purchases, the position here was that a number of firms, anticipating a shortage in supplies during 1960, found themselves forced to order steel from continental sources. In support of their purchases, application had been made on behalf of the Association for a relaxation in import duties; the application was still being considered by the Board of Trade.

Labour and Welfare Committee

Mr. M. C. Vaughan then spoke of the work on the Labour and Welfare Committee.

An induction course for young entrants had been held last autumn. This was the first venture of its kind and comprised 18 boys on the four sessions. Drop forgers were still having the active support of the Bilston College on the training of operatives under the City and Guilds of London scheme, and a similar course was continuing at Sheffield.

Mr. Vaughan said that the committee had recently visited Sheffield and studied a co-operative training scheme which was being run by a group of Sheffield forgemasters for their trainee hammermen. They had found it very interesting, and hoped that in the not too distant future they could start a scheme for their own industry modelled on it. It was a course of two years' duration with about a dozen boys in both of the first- and second-year courses. The great point about this scheme was that the boys were treated purely as trainees for the whole of the two years that they were in the course; they were not put on to team work and consequently the objection did not arise that the boys wanted to be taken off their piece-work jobs to take training.

Foremen's conferences were still being held. Last year the conference had been held in Sheffield, the English Steel Corporation acting as hosts, and the one this year would be at Birmingham and would be devoted to the study of training young people.

They were always concerned with safety in works and noted with satisfaction the low and reducing rate of accidents caused by machinery in this trade. At the same time too many injuries continued to arise from strains and accidents caused by lifting and damage to feet. It was urged that firms should encourage the wearing of safety boots, fireproof clothing and goggles.

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Straightening hardened steel tools

Use of austenitic transformation influenced by small stresses

DOC.MGR.ING. E. ZMIHORSKII

APPLICATION of the speed change effect of austenite transformation under the influence of small stresses correctly applied to hardened objects during their gradual cooling has been used to develop a method of straightening hardened steel products.

The method is simple, reliable and accurate, especially in the production of long expensive machine-tool elements such as the high-speed steel broaches used for finishing the interior of roughly drilled holes in metals. Conventional methods consist mainly in inducing surface stresses by percussion, to effect straightening within the limits of elastic deformation. Long precision tools so treated, however, may lose their straightness during use or during storage.

The author's patented method of straightening or otherwise shaping hardened steel elements consists in accelerating austenite transformation into martensite in those areas of hardening where tensile stresses appear and in retardation of martensite formation caused by compressive stresses. The formation of martensite in a hardened bar subjected to bending begins earlier and in larger quantity in the side under tension, but it starts later, at a lower temperature, and develops in smaller quantity in the compressed side of the bar. Since the specific volume of martensite is larger than that of austenite and indeed, of all other structures, it is possible to control its transformation by shaping or straightening, using suitably applied forces, but it is unnecessary for these forces to exceed the elastic limit of the material. Indeed, the degree of applied stress lies considerably below the limit of elastic deformation.

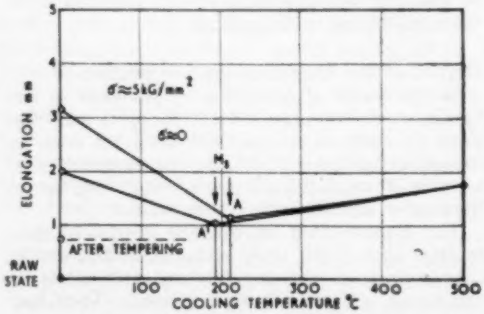
The straightening of hardened broaches is achieved by applying small static bending forces at the temperature when transformation of austenite into martensite begins. The basic condition of correct straightening is the force/action time rather than the actual force applied. Considerable force applied for a short period causes little or no permanent deformation; on the other hand, a smaller force applied for a sufficiently long period can produce a large degree of deformation. In this simple manner the difficult operation of straightening can be achieved safely and with no risk of fracturing hardened material.

Tools after salt-bath hardening are still of austenitic structure when straightening or shaping takes place. The process must begin from the temperature of martensite transformation M_s, or rather from a point preceding it, because of temperature increase caused by stretching. Since the transformation of austenite into martensite proceeds over a wide range of temperatures, the process of straightening is facilitated. The exact temperature, for a given steel, depends on its chemical composition, hardening temperature and to some extent upon mass.

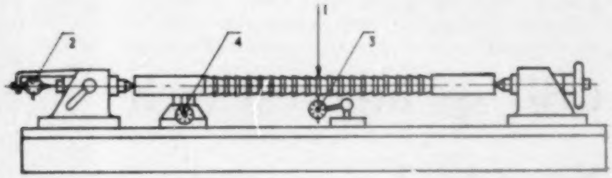
In practice, the range of temperatures and period of straightening may be determined by temperature, or magnetic measurements. The range of temperatures for straightening or shaping high-speed steel tools is approximately 250 to 50°C.

Investigations carried out by industrial users confirm that articles straightened or shaped by the process outlined keep their form indefinitely.

Fig. 1 shows elongation changes of a C 0·85, Cr 4·0, W 9·0 and V 2·0% high-speed steel shaft during continuous cooling in air after removal from salt bath at 500°C. after gradual hardening. It can be seen that in some areas there are no elongation stresses ($\sigma=0$), or these are less; final elonga-



1 *Length changes of a hardened high-speed steel shaft during continuous air-cooling after removal from salt bath at 500°C.*

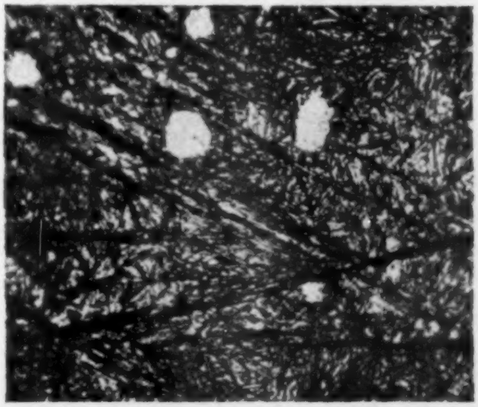


3 *Device for straightening long hardened steel products*

tion after transformation is also less. Explanation of this phenomenon is that the direction of constituent layers of martensite is approximately co-ordinated with that of elongation stresses. In material on the stretched side the martensite layers are more or less parallel to the surface of the bar being bent, this resulting in greater and more lasting elongation on the stretched side than on the compressed side where the retarded martensite layers are not parallel to the direction of compressive stresses. However, in spite of their lesser volume they will, as stresses vanish, key the martensite layers in a longitudinal direction as on the other side of the bar.

Fig. 2 shows the structure of high-speed steel similar to that referred to in fig. 1, after hardening and tempering. Almost horizontal and also at an angle of 30° layers of martensite are seen keyed to small needles of martensite. The bending influence is to be observed only from the point A (fig. 1).

Fig. 3 illustrates a device for straightening hardened steel broaches or similar products by the method outlined. It provides an easy and accurate method which saves time otherwise spent in grinding each piece to ensure the necessary degree of straightness. Moreover, it avoids the harmful effects of surface tempering of hardened surfaces caused by the grinding process.



2 *Structure of high-speed steel similar to that referred to in fig.* 1 *after hardening and tempering. Direction of stretching is horizontal* ×600

After checking the deflection of the tool to be straightened, pressure is applied at point 1. The effect of straightening is to elongate the tool, which increases the drag caused by friction at the lathe centres during rotation. For measuring elongation which in this case is a function of straightness a device 2 with dial indicator is suitably mounted. A similar device 3 gives a direct indication of straightness as also does the magnetic measuring appliance 4 which may be employed if necessary.

Nat. Assoc. of Drop Forgers

concluded from page 165

The public were becoming more and more conscious of the problem of noise. Many irresponsible statements had been made in the Press about the effects of noise, but these claims could only be proved or disproved by clinical study over a period of years. He believed that present noise-measuring apparatuses were incapable of measuring the impact noises which were characteristic of a drop forge.

The Trades Unions were seeking all the information they could about the health effects of noise on their members, and a Royal Commission was being appointed to investigate. The Association was keeping a very close watch on developments in the interests of its members, because this was a topic which would loom increasingly large in coming years.

Presentations

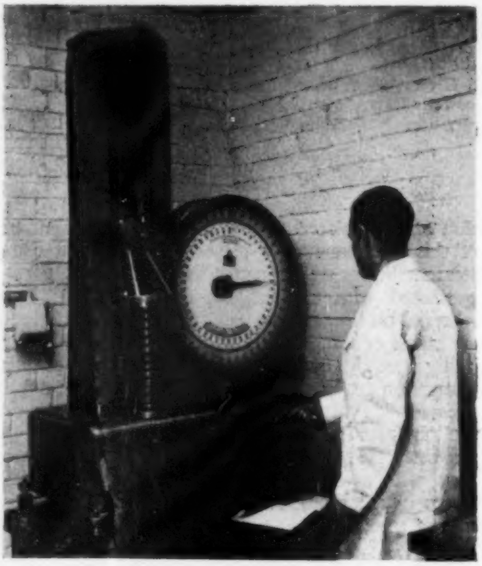
The president presented the immediate past-president with a silver cigarette box, suitably engraved, accompanied by a scroll bearing the names of members of the Governing Council, being a gift from members of the Governing Council as a token of their respect.

An award of £25 under the NADFS prize scheme was made by the president to Mr. W. J. M. Moore (Rolls-Royce Ltd.) for his paper, 'The development of forging for the jet engine.'

Coil spring research

New laboratories opened

New laboratories for the Coil Spring Federation Research Organization at Sheffield, which were opened last month by Sir Harry Melville, K.C.B., F.R.S., *Secretary of the Department of Scientific and Industrial Research, are among the most comprehensive of their kind in the world. They will enable research to be carried out on springs made from the finest wires to bars of up to 2 in. dia. In addition to work on springs and torsion bars, research will be possible on materials in wire and strip form; and metallurgical investigations will be undertaken on a very wide range of ferrous and non-ferrous alloys*



Loads of up to 1 ton are applied by this machine to study the load/deflection characteristics of heavy springs

THE SPRING as we know it—which may be a leaf-spring, a coil-spring or a torsion bar—was first made in Britain about 200 years ago. Spring making soon became an important craft, and manufacturing centres grew up in the Black Country, in Yorkshire, in Rochdale and in Redditch. These are still the most important centres, producing millions of springs, of all shapes and sizes, for the engineering industry generally.

Only 30 years ago springs were almost entirely the product of craftsmen, being developed largely on empirical lines. Scientists exerted no real influence on the industry until the second world war, when the special needs of aircraft, tanks and new weapons demanded exceptional qualities. The spring had to stand up to unusual conditions and there was no room for failure. The industry met this challenge by adopting the idea of co-operative research and the Coil Spring Federation Research Organization was born. It is still a comparatively small research group, but in the last three years, since it was reorganized as an active centre for spring research, its contribution to fundamental knowledge—and applied techniques—is increasing rapidly.

Until 1957, all CSFRO investigations on spring research were carried out on an extra-mural basis in the universities. Now, most of the research is being done in the CSFRO headquarters at Sheffield, next door to the laboratories of the British Iron and Steel Research Association, which has helped its junior partner so much to get on its feet. But the link with the universities is still maintained, and at least two of the projects on the current research programme are being investigated by university departments.

The spring-making industry is quite small, employing only about 7,000 people and with a total turnover in the region of £5,000,000. It is made up mainly of a number of small companies, most of whom have less than a hundred people on the pay roll. But because the spring is universally employed, research is essential. The CSFRO has a total membership of nearly 100, of which only half are spring makers, the rest being manufacturers in the supplier or user industries.

The CSFRO receives a grant of £4,300 a year from the Department of Scientific and Industrial Research and, as it grows in the future, it hopes to attain full research association status.

Laboratories and equipment

The two-storey laboratory block recently completed in Doncaster Street, Sheffield, is probably the most comprehensive of its kind for research into all forms of spring and spring materials.

The ground floor contains laboratories for heavy-fatigue testing, general mechanical testing, experi-

mental heat treatment and electro-plating. In the fatigue testing laboratory are housed 12½-h.p. machines capable of applying a dynamic load of 9 tons, which are used for fatigue testing heavy coil springs. Up to 18 springs may be tested at one time. Other machines used for fatigue testing springs of the internal-combustion-engine type are capable of infinitely variable speeds of compression of up to 4,000/min. A special feature of this laboratory is the sound-proofing and anti-vibration features incorporated in both the suspended ceiling and the floor.

The mechanical testing laboratory houses a variety of conventional machines used for determining the properties of both specimens and springs, covering the range of material diameters 0·004–2·0 in. One machine, for example, is capable of developing a maximum torque of 120,000 lb. in. and is used to investigate the effects of hardenability on the static torsional properties of large-diameter spring steel bars.

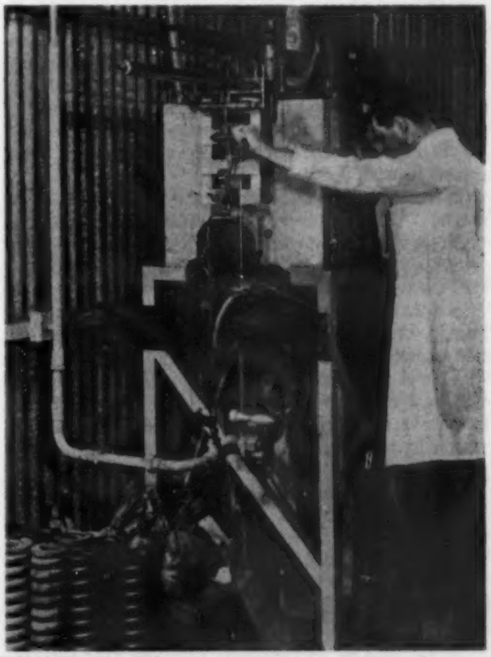
There is a comprehensive range of machines, capable of applying static loads from a few ounces up to 30 tons. The determination of fatigue characteristics of drawn wires of diameters 0·01–0·25 in. is provided for by high-speed rotating-beam fatigue machines, which can complete up to 100 million cycles in as little time as one week.

The study of corrosion and protection of spring materials and the effects of hydrogen embrittlement due to electroplating is being continued in a new laboratory specially fitted out for this purpose. Facilities are available for electroplating copper, zinc, tin, cadmium and nickel, and the experimental heat-treatment laboratory is equipped with fully instrumented electric furnaces.

The laboratories contain a number of machine tools and a shot-peening unit which automatically rotates the object under treatment while at the same time traversing it with the shot stream.

The first floor is devoted to light laboratories (containing small static testing machines, general scientific instruments and equipment), administrative offices and a conference room. The materials testing laboratory contains machines for determining macro-hardness, tensile and torsional properties of wires and load-deflection characteristics of small springs. Metallographic facilities are provided in specially fitted rooms for rough sample preparation, fine polishing and etching, microscopical examination and photography.

The laboratories were built at a cost of £22,000 and new equipment totalled another £25,000.



ABOVE *Shot-peening plant for experimental use on spring materials*

LEFT *Multiple fatigue testing of heavy hot-formed springs with max. load of 8½-tons on 12½ h.p. radial machine*

Research programme

Since the first world war, alloy steels have become increasingly important as spring materials, although carbon steel is still very widely used. The spring maker has unique problems, because of the way a spring is loaded or stressed. There are only a very few other applications of metal where the material is stressed in torsion, which is one essential reason for the spring industry to carry out its own research.

In the second world war, government contracts called for rigid specifications and these were among the first 'standards' to be laid down in the British industry. In 1947 the British Standards Institution introduced its first standard on springs.

Today, it is the research organization which very often sets the 'standards' as a result of its investigations. The research programme for the next two or three years contains many important projects, but perhaps the most significant is that the ceiling for high-temperature research has been raised from 500–850°C.

What sort of problem is the research worker facing? For example, while ambient temperature changes are not serious factors, the atmosphere in which the spring has to operate can be most important as corrosion can accelerate failure. In corrosive atmospheres, such as in a chemical plant, the spring must be protected, either by metallic or non-metallic coatings.

This is not necessarily a straightforward application as it can lead to other problems. One of these is hydrogen embrittlement due to electroplating, in which hydrogen produced during the cleaning and plating processes actually enters the steel, causing premature failure. Some of the earliest work of the CSFRO was directed at this problem producing very valuable information. The electroplating equipment donated by W. Canning & Co. Ltd., Birmingham, will be invaluable in taking the research a stage further and, it is hoped, finally to a solution.

In the field of non-metallic coatings the CSFRO is exploring the application of new resinous and plastic materials to springs through an extra-mural project being carried out at the engineering department of Imperial College, London.

Another extra-mural project is research into the metallurgy of copper beryllium as a spring material, which is being carried out in the metallurgy department of Sheffield University.

For high-temperature use the Research Organization is seeking springs which will perform satisfactorily without creep.

The director and his small team of scientists are also seeking a material with the properties of titanium but with a higher modulus of elasticity. Titanium has even higher corrosion resistance than stainless steel, high tensile strength and low density. It could be used much more for springs if it had a higher modulus of elasticity, and alloying additions can help in this respect. A good deal of research has already been done on alloys of titanium in wire form, and actual springs made of these materials are now being studied.

With this increasing store of knowledge, the metallurgists at CSFRO are in a unique position to advise design engineers in industry on the selection of materials. This is especially important in cases where design requirements have advanced beyond existing spring specifications as, obviously, new designs may need new spring materials.

Ultra-high-strength steels

concluded from facing page

TABLE I. *Chemical composition of the ultra-high-strength steels*

	%
Carbon	0·40
Manganese	0·75
Silicon	1·60
Nickel	1·80
Chromium	0·85
Molybdenum	0·30
Titanium	0·10
Boron	0·003

Preliminary experiments were carried out to determine the critical temperatures, the M_s temperature and the maximum time that the steels could be held above the M_s temperature before transformation to other constituents occurred.

Treatments using oil or air quenches were also studied. A conventional oil quench from 900°C., followed by double tempering in the temperature range 200 to 260°C., produced the best all-round

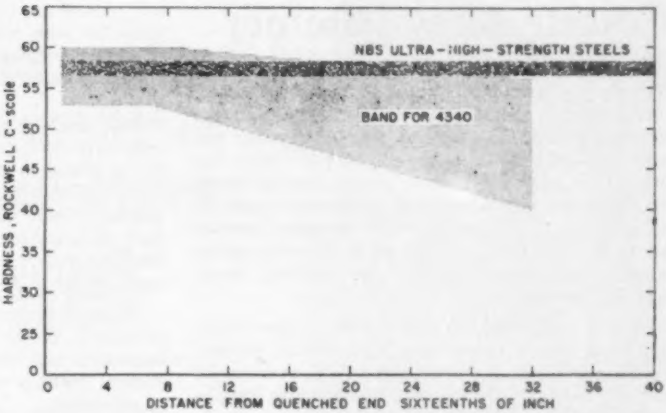
TABLE II. *Mechanical properties of the ultra-high-strength steels*

Hardness (Rockwell C scale)	53
Ultimate tensile strength (lb./sq. in.)	285,000
Yield strength (lb./sq. in.)	235,000
Elongation, 1·4-in. gauge-length (%)	10
Reduction in area (%)	35
Charpy (V-notch) impact strength (ft.-lb.)	
At room temperature	16
At –40°F.	16

properties, so this heat treatment was used for all subsequent tests of the promising steels.

Although boron apparently has no particularly beneficial effect on the properties of the steels, neither does it appear to have any detrimental effect. In steel structures appreciably larger in cross-section than those tested, the beneficial effect of boron in improving hardenability may be advantageous. It is believed that the properties obtained on the laboratory steels could be duplicated or even improved in well-made commercial steels.

Ultra-high-strength steels



End-quench hardenability band for two of the U.S. National Bureau of Standards' ultra-high-strength steels superimposed on the hardenability band of AISI 4340 steel

The U.S. National Bureau of Standards has experimentally produced an ultra-high-strength steel that can be heat treated to a strength of 285,000 lb./sq. in. with sufficient ductility for structural applications. Developed at the Bureau's thermal metallurgy laboratory, the steel is made by normal melting and working processes.

In recent years the increasing demand for reduced weight in aircraft structures has been a constant stimulus for the development of high-strength steels. One of the principal applications for such materials is in aircraft landing gears. Since landing gears constitute approximately 10% of the weight of an empty military plane, the use of an ultra-high-strength steel in such components can save considerable dead weight with a corresponding increase in load-carrying ability. Because of the urgent need for stronger steels in this particular application, the U.S. Navy Bureau of Aeronautics has sponsored an investigation at the Bureau to develop a steel having a tensile strength of approximately 300,000 lb./sq. in.

Although many steels can be heat treated to strengths of 300,000 lb./sq. in and higher, they are normally brittle at this strength level. Such brittleness prohibits their use in structural applications where a certain amount of ductility and toughness is required. The present investigation therefore concentrated on developing a steel that would not only be strong but would also have a high impact resistance.

Preliminary considerations indicated that the strength level desired could not be obtained in structural steel containing less than about 0·40°C. if the steel were to be given some form of tempering treatment subsequent to hardening. In addition, the steel would require considerable amounts of alloying elements in order to transform completely to martensite so that large components, such as landing gears, could be hardened throughout. The experimental steels were therefore based on AISI 4340 modified as desired. Boron was added to a split of each melt, since previous studies had indicated that boron increases hardenability and has a beneficial effect upon the impact properties of some steels at room temperature and below.

Tests on 40 experimental steels

Over 40 experimental steels were melted in the Bureau's foundry. These were forged and rolled into ⅝-in., ⅞-in., and 1¼-in. plates, which were then normalized and annealed. Tensile, Charpy impact (V-notch), and Jominy (end-quench) hardenability specimens were machined from the different thicknesses. The tensile and impact specimens were heat treated by six different methods, and the tensile impact and hardness properties of the various specimens then determined.

One particular composition appeared to have an excellent combination of strength and ductility. This was a steel based on AISI 4340 modified by the addition of silicon and titanium. Additional melts were made to check the results obtained on specimens from the original steel. The tests confirmed an ultimate tensile strength for the steel of approximately 285,000 lb./sq. in. and an impact resistance of 16 ft.-lb. at both +20 and -40°C. The composition and nominal mechanical properties of the steel are given in Tables I and II. Even better ductility and toughness properties were obtained on a single heat that was vacuum remelted.

continued on facing page

Counterblow hammer

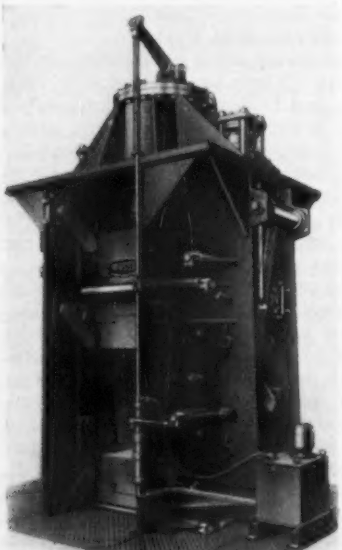
THE forerunner of the Massey counterblow hammer was originally designed thirty years ago, but the demand at that time for this type of hammer was very limited. However, in recent years there has been a considerable increase in the interest shown by drop forgers in this type of hammer, and in view of this, the design has been completely revised by B. & S. Massey Ltd. to meet the very severe working conditions imposed by modern drop-forging practices.

A new and unique feature of this design is the belt coupling compensating gear which ensures equal tension at all times in the belts that couple the top and bottom tups, thus considerably lengthening the life of the belts.

Compensating gear for belt couplings

Synchronized movement of the upper and lower tups is ensured by means of a mechanical coupling. Two couplings are provided, one at each side of the hammer, the reverse motion being transmitted by steel belts with special lightweight connections made in steel. A shock absorber is provided for each tup connection, which consists of a flanged sleeve and a pack of alternate steel and rubber washers. The alloy steel adjusting bolts, which are pinned to the connections of the belts, are provided with spherical seatings to minimize the off-centre loading on the connection due to the changing angle of inclination of the coupling with the tups. To ensure equal loading of the two pulley assemblies, they are provided with compensating cells, connected hydraulically. Each cell has a glandless expansion joint, the sealing unit being a well-tried proprietary bellows of laminated stainless steel. The cell is filled with a viscous fluid of a stable silicone base and is designed so that the bellows is not subjected to momentary impact loads.

A considerable differential movement can be permitted in the couplings before adjustment is necessary, and an indicator is provided in a convenient position which shows at a glance the state of adjustment. This special compensating feature ensures equal belt tensions at all times, and avoids offset loading on the tups which may cause tilting in the slideways and premature failure of the belt.



Massey counterblow hammer

Hump-back mesh-belt conveyor furnace

An essential requirement for the treatment of stainless and heat-resisting alloys is a protective atmosphere of utmost purity. Either hydrogen or a hydrogen-nitrogen mixture derived from ammonia is the atmosphere gas generally used. The hump-back furnace made by Birlec Ltd. is specially designed for this purpose. It is rated at 20 kW., with a conveyor belt 6 in. wide to carry work continuously through the treatment process. The furnace itself consists of an inlet tunnel, a heating chamber with a nickel chromium muffle to contain the protective atmosphere and a double-cased, water-jacketed cooling chamber through which passes the belt carrying the charge. To reduce atmosphere and heat losses there are sliding counterbalanced shutters in the extreme ends of the entry and exit tunnels which are normally opened just sufficiently to clear the work on the belt. The heating chamber is lined with high-quality semi-refractory insulation suitably graded to reduce heat losses: it is heated by easily removable silicon carbide rods placed transversely above and below the muffle. These are connected to the secondary terminals of a double-wound step-down transformer, the low voltage of which is variable over a wide range to compensate for increasing resistance as the elements 'age' in service.

The electrical power input to these resistors is controlled by a contactor which is automatically operated by a temperature-control instrument connected to a platinum/platinum rhodium thermocouple mounted in the roof of the heating chamber. Temperatures up to 1,200°C. can be safely maintained.

The conveyor belt, of woven nickel chromium wire mesh, is driven by a $\frac{1}{2}$-h.p., 1,440-r.p.m. electric motor operating through a hydraulic variable-speed gear, a 2,000 : 1 double-reduction gearbox and a roller chain drive to the driving drum. Wide-range speed control caters for varying work-loading densities on the conveyor belt. An auxiliary conveyor drive is fitted below the portion of the mesh belt in the upward sloping inlet tunnel, designed to assist the passage of the belt up the incline. This device, in conjunction with the arrangement of the main belt drive, ensures minimum stress in the heated section of the belt and long belt life.

NEWS

Wiggin nickel alloys in industry

LAST MONTH, an exhibition of Wiggin nickel alloys was held at Park Lane House, London, W.1. The aim of the exhibition, the second to be held in London by Henry Wiggin & Co. Ltd., was to help engineers and designers to make the best use of the company's specialized high-nickel alloys.

These alloys fall mainly into four groups, corrosion resisting, heat resisting, electrical resistance and materials with special physical properties. The exhibition included demonstrations of these properties and indicated correct methods of fabrication of the alloys.

The industrial applications of Wiggin high-nickel alloys were also shown by a large selection of actual components, sub-assemblies and finished parts in which the Wiggin materials play vital parts. Among the applications were examples of Wiggin alloys in the aircraft industry, including a Nimonic 80A catalyst pack-retaining grid for a Super-Sprite rocket motor by the de Havilland Engine Co. Ltd., and the disc and blades of a gas turbine rotor employing Nimonic creep-resisting alloys by Bristol Siddeley Engines Ltd. The marine field included an example of a variable pitch propeller with blade roots of K Monel by Slack & Parr (Marine) Ltd., and under the heading 'Chemical Plant' was included a hot-pressed dished head in Corronel 210 by G. A. Harvey & Co. (London) Ltd. In the electrical field was shown a Saferod heater with an Inconel sheath enclosing the Brightray C element by Heatrae Ltd., and in electronics, as an example, was included the printed circuits of an Avometer made in Ferry resistance alloy, by Technograph Printed Circuits Ltd.

Other fields where examples were shown included furnace equipment for the metal, ceramic, vitreous enamelling and glass industries.

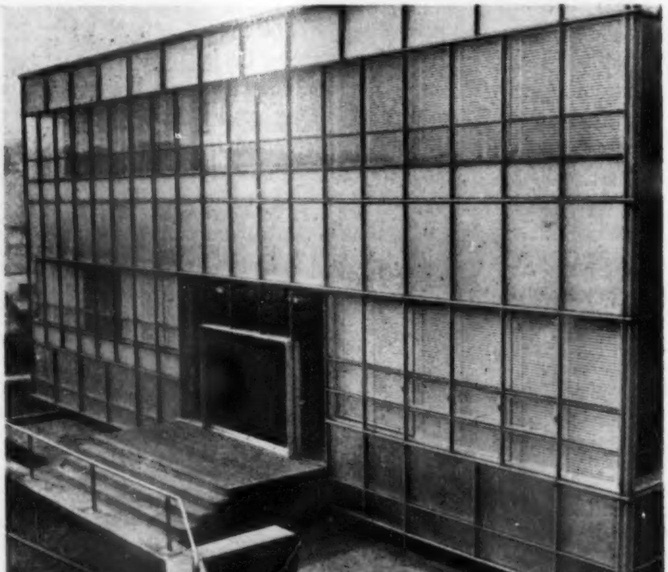
The exhibits of properties and applications helped to show how the need for the company's specialized alloys is increasing and emphasized the considerable amount of research work being carried out to develop these series of alloys in their particular fields.

Fan manufacturers open exhibition building

Perhaps the most interesting single display in the new permanent exhibition building at the Tottenham, London, N.17, head office address of Keith Blackman Ltd., makers of the 'Tornado' range of fan engineering and industrial gas equipment, is a pair of propeller fans. Both were made by Keith Blackman, both are direct driven by motors made by Keith Blackman, both are of approximately 12 in. diameter. Here the similarity ends for one was made in 1897, the other in 1959. The veteran fan is in fact one that was returned to Tottenham after 54 years' continuous service in ventilating office accommodation in a town hall. It was still in working order but unsuited to a pending change in electric supply.

The new, specially-built showroom is designed to show users, prospective users, trade associations and student bodies a broad cross-section of the small to medium ranges of 'Tornado' fans and ancillary equipment 'in the flesh.'

Stainless-steel cladding for new chemical laboratory



Extensive use of stainless steel has been made in the construction of a new two-storey chemical laboratory at the Stocksbridge works, near Sheffield, of Samuel Fox & Co. Ltd., a subsidiary of the United Steel Companies Ltd.

An outstanding feature of the building, which centralizes the work previously carried on in several separate laboratories, is the employment of stainless steel as an external wall cladding. The wall panels consist of 26-gauge stainless steel sheets, diamond patterned, and electro-polished to a matt finish which prevents glare and reflectivity. The sheets are bonded to half-inch Asbestolux board. The steel is Silver Fox 20, containing 18% chrome and 8% nickel.

The curtain walling was supplied and erected by the Crittall Manufacturing Co. Ltd. and is one of the first examples of their Fenestra 237 system, which makes use of Neoprene as a bedding material, thus eliminating much of the caulking work associated with conventional systems.

Another interesting feature of the curtain wall is that the main structural extrusions are horizontal and are positioned where a horizontal division is predetermined by the ceiling and cill heights. This gives freedom to the architect to position the vertical members where they are best suited for spandrels and glazing, and has enabled the number of wall panel sizes to be kept to a minimum.

Uranium in S.W. England

The reconnaissance survey for uranium, carried out by the Atomic Energy Division of the Geological Survey in the last two years, is now virtually complete.

Seventy new occurrences of uranium have been found during the course of operations which have included an aerial survey of Cornwall, Devon and much of Somerset, as well as surface mapping, excavating and drilling at promising localities. No deposit of economic importance has been discovered and it is concluded that if any are present they are covered to such a depth with soil or overburden that they are unlikely to be detected by existing instruments.

Although no deposit estimated to contain more than 5 tons of uranium oxide has been found as a result of this survey, the south-west of England uranium province has served for many years as an ideal testing ground for British geological electronic equipment.

The study of uranium occurrences in Cornwall and Devon, started in 1945, has played an important part in the discovery of uranium in the Commonwealth, while recent work has contributed considerably to the development of aeroradiometric surveying techniques. A scientific assessment of the aerial survey technique, read at the 1958 Geneva Conference on the Peaceful Uses of Atomic Energy, has been acclaimed as one of the more important papers presented at these meetings. Thus it can be said that, although no important reserve of ore has been proved in the south-west province, the work undertaken has been fully justified.

Classified advertisements—contd.

SITUATIONS VACANT—continued

METALLURGIST required, capable of taking charge of small Heat Treatment Plant undertaking sub-contract work, with ability to extend existing business by contacting potential customers. Practical experience on gas-fired Muffle and Salt-bath Furnaces essential with good theoretical background. Excellent opportunity for advancement in small progressive Company in new Factory in S.W. London area. Applicants should state experience and salary required to Box ME127, METAL TREATMENT AND DROP FORGING.

MACHINERY WANTED

TWO BATCH-TYPE ELECTRIC FURNACES, 20 kW. or 30 kW. One forced-air Circulating Tempering Furnace, 20 kW. Full details and particulars to Box WA128, METAL TREATMENT AND DROP FORGING.

MACHINERY FOR SALE

ERIE 8,000-lb. HAMMER, new 1938, unused since 1947, no defects. Operation by steam or air. Dismantled. Available immediately.—Box ER126, Metal Treatment and Drop Forging.

Classified advertisements—contd.

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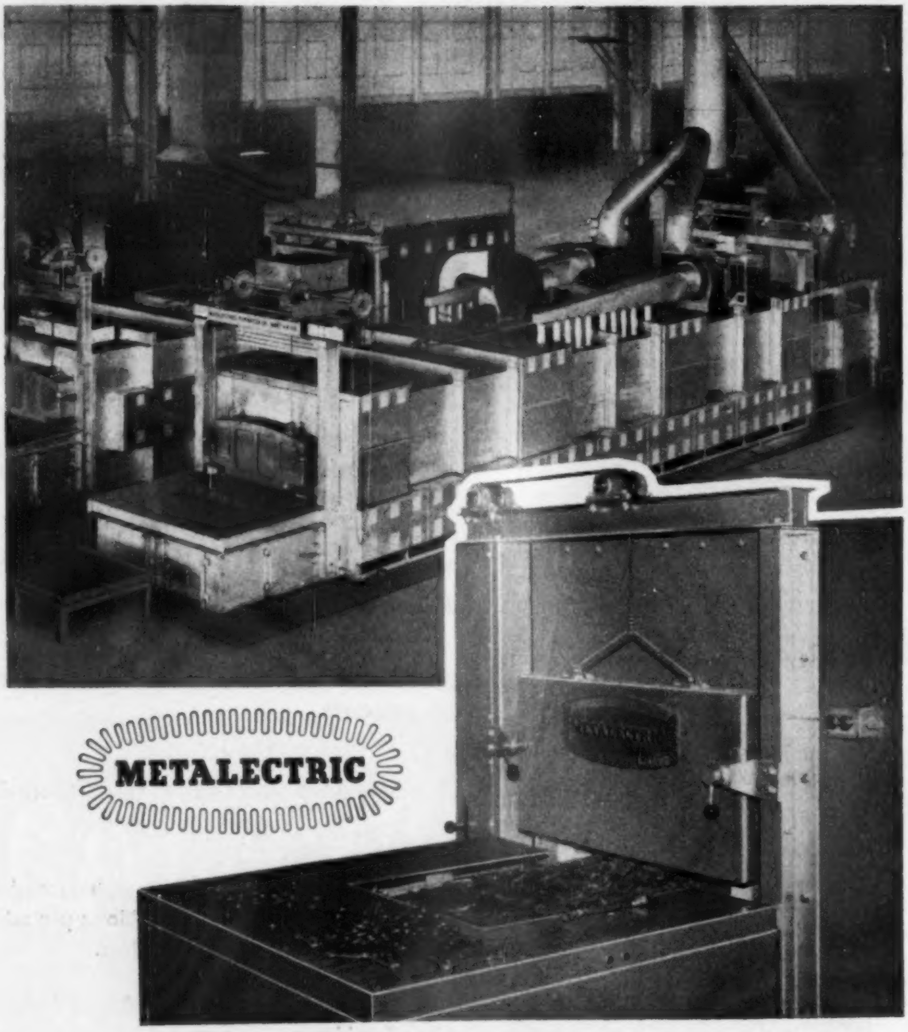

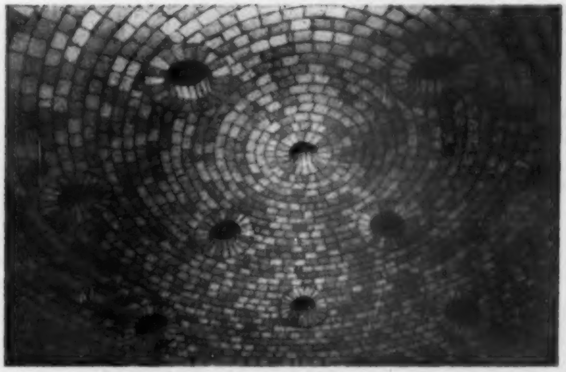

We take our own medicine

Five years ago we began rebuilding the round down-draught kilns of The Morgan Crucible Co. Ltd. at Battersea in MI. 28—a hot-face insulating brick of low thermal capacity that was then comparatively new. The roof of one of these furnaces immediately after installation is shown in the first picture.

. . . (MI. 28 bricks)

. . . and like it

The output of these kilns, lined with MI. 28, was considerably greater than their firebrick counterparts, because the low heat-storage of the lining shortened both heating and cooling periods. This, in fact, was the principal reason for the change-over. What we were not so sure of at that time was the life of these linings. We would hardly have dared to expect anything as good as we got. The second picture shows the same roof after *five years* service. So far as we can see it is good for at least another five years and probably longer.

MORGAN Refractories Ltd

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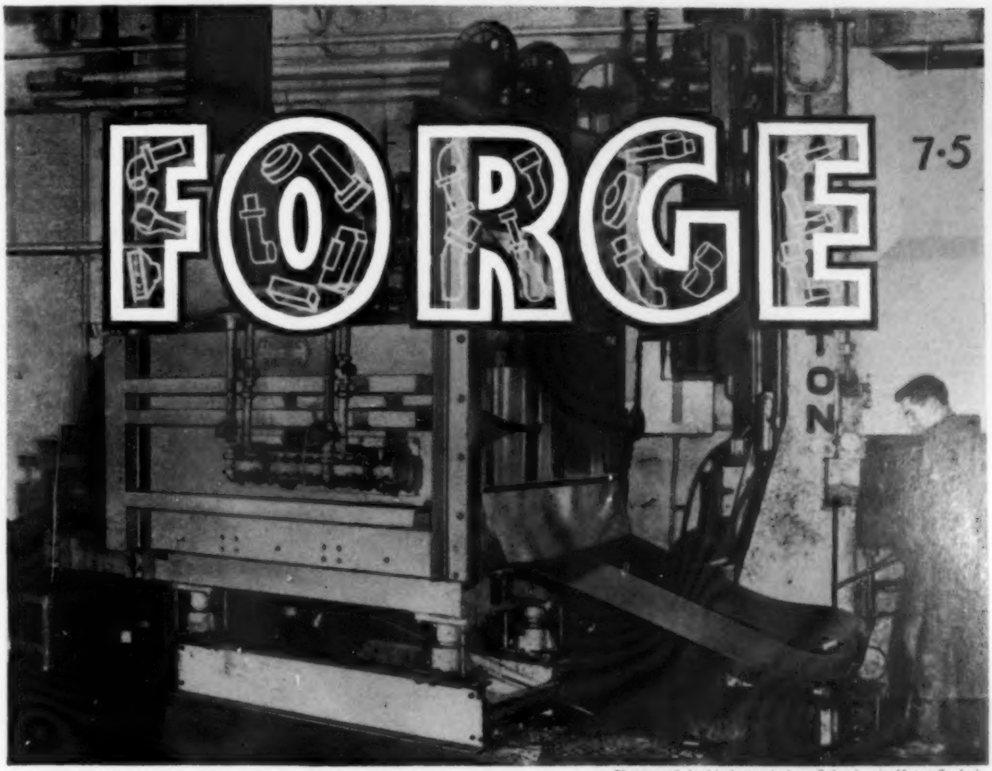
THERMIC

Mechanised



Photograph by kind permission of the Austin Motor Co. Ltd.

FURNACES

A wide range of standard or tailor-made mechanised forge furnaces is available, Pusher Type - Rotary Hearth Type - Conveyorised Bar End Heating, with GGC scale-free heating system or fired by gas or oil. The photograph above illustrates a small Thermic Magazine Feed Pusher furnace fired by CC Burners. Output: 7-cwts. of small billets per hour.

Thermic Equipment & Engineering Co. Ltd.

(Subsidiary Company of Gibbons Bros. Limited, Dudley)

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metal treatment

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